NBSIR 82-2483

Volume 18

HUD UTILITIES DEMONSTRATION SERIES

PERFORMANCE ANALYSIS OF THE JERSEY CITY TOTAL ENERGY SITE: EXECUTIVE SUMMARY

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Engineering Laboratory
Center for Building Technology
Washington, DC 20234

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MODULAR INTEGRATED UTILITY SYSTEMS

improving community utility services — supplying electricity, heating, cooling, and water/ processing liquid and solid wastes/ conserving energy and natural resources/ minimizing environmental impact

Prepared for:
Department of Housing and Urban Development
Energy, Building Technology and Standards Division
Office of Policy Development and Research
Washington, DC 20410

MARCH 1982

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

Abstract

Under the sponsorship of the Department of Housing and Urban Development (HUD), the National Bureau of Standards gathered engineering and economic data from an apartment/commercial complex located on a 6.35 acre (2.6 hectare) site in Jersey City, New Jersey. The complex includes four medium and high rise apartment buildings totalling 486 dwellings, a 46,000 ft^2 (4270 m^2) commercial building, a school, a swimming pool, and a central equipment building.

The construction of the complex was started in 1971, after a decision by HUD to design the central equipment building to produce both the thermal and electrical energy required by the site, and to install the necessary equipment to recover the waste heat from the diesel engines driving the generators. The central equipment building was designed as a total energy (TE) plant utilizing absorption type chillers, and has been serving the complex since January 1974.

The National Bureau of Standards was responsible for instrumenting the plant and site buildings and recording engineering data utilizing an automatic data acquisition system (DAS). The DAS was put on-line in April 1975. These data were processed by minicomputer at NBS to obtain the desired hourly, daily, monthly and annual values and profiles of engineering measurements and/or derived variables computed from the engineering measurements and other related data.

Economic, reliability and environmental data were also collected and analyzed by NBS in conjunction with an analysis of the engineering data. This report presents an "Executive Summary" of the final report on the performance analysis of the Jersey City Total Energy Project. The reader is encouraged to refer to that final report for further details.

The analysis of the engineering data clearly indicates a significant savings in fuel by using the total energy concept in the plant. Several areas were also identified by this analysis where minor modifications in the plant operation could result in additional fuel savings. Three of the modifications have already been incorporated in the present plant operational procedures.

The analysis of the reliability of the utility services at the site indicated services were being supplied to the consumers at an acceptable level within the reliability targets set and achieved by many utility companies. Environmental tests were made at the site for the effects of the plant on air quality and noise. Nitrogen oxides (NO_x) were the only detectable combustion pollutants from the plant. However, with the existing high background NO_x levels in the area, the contribution from the TE plant could be classified as incremental. The noise level was below the daytime local noise ordinances at the buildings adjacent to the plant. The environmental effects of the cooling tower were well within acceptable limits.

Economic analyses were made on the plant as operated during the study and on a comparative basis with twelve alternative systems. In general, those alternative systems utilizing the total energy concept showed a significant savings in fuel, but the economics of such systems were marginal compared to conventional type systems based on 1977/1978 economics.

Key Words: Absorption chiller; boiler performance; diesel engine performance; engine-generator efficiency; integrated utility system; total energy systems-economic and engineering analysis; waste heat recovery.

Table of Contents

Disclaimer

Certain commercial equipment and instrumentation and data acquisition systems are identified by name in this report in order to adequately describe the capabilities and technical features of hardware used in the instrumentation system. In no case does such identification imply recommendation or endorsement by the National Bureau of Standards, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.

SI CONVERSIONS

In view of the presently accepted practice of the building industry in the United States and the structure of the computer software used in this project, common U.S. units of measurement have been used in this report. In recognition of the United States as a signatory to the General Conference of Weights and Measures, which gave official status to the SI system of units in 1960, appropriate conversion factors have been provided in the table below. The reader interested in making further use of the coherent system of SI units is referred to NBS SP330, 1972 Edition, "The International System of Units," or E380-72, ASTM Metric Practice Guide (American National Standard Z210.1).

Metric Conversion Factors

Length	1 inch (in) = 25.4 millimeters (mm) 1 foot (ft) = 0.3048 meter (m)
Area	1 ft^2 = 0.092903 m^2
Volume	1 ft^3 = 0.028317 m^3
Temperature	F = 9/5 C + 32
Temperature Interval	1 F = 5/9 C or K
Mass	1 pound (lb) = 0.453592 kilogram (kg)
Mass Per Unit Volume	1 lb/ft^3 = 15.0185 kg/m^3
Energy	1 Btu = 1.05506 kilojoules (kJ)
Specific Heat	1 Btu/[(lb) (°F)] = 4.1868 kJ/[(kg) (K)]
Gallon	1 gallon = 0.0037854 m^3

1. INTRODUCTION

This is an executive summary of the major results contained in the document: Performance Analysis of the Jersey City Total Energy Site: Final Report, HUD Utilities Demonstration Series, Volume 13, NBSIR 82-2474. In this executive summary, a brief background of the project and a limited description of the site are given. Fundamental engineering data are presented as well as an analysis of the engineering performance of the plant, plant components and distribution systems. A brief overview of the results of a series of environmental analyses is also presented.

An overview of the economic evaluation of the plant is presented with the results of an analysis of the fundamental costs of the various components and services of the plant. The results of a study of alternative systems are presented with the relative costs and energy requirements of each system. The plant in its present configuration was used as a reference or base line in this study of alternative systems.

The reader who is interested in any specific area or areas of the project is encouraged to refer to the final report cited above for further information and the conditions under which the data were derived and are presented.

1.1 TOTAL ENERGY CONCEPT

The generation of electrical energy by conventional means uses less than 40 percent of the available energy in the coal, fuel oil, or gas firing the boilers to produce steam for driving turbines. The remaining 60 percent is usually rejected into the environment as waste heat. In the total energy (TE) concept, every effort is made to recover this waste heat and utilize it for other needs of the surrounding community. Space heating, domestic hot water, and space cooling utilizing absorption chillers are the typical applications of this waste heat.

The total energy (TE) concept in the United States was originally encouraged by the natural gas utilities. However, due to technical and operational problems, as well as concern about the unavailability of natural gas, this implementation of TE fell to lower levels. The energy crisis has again increased the interests in TE. Some of the recent initiatives in the development of TE have been encouraged largely as a part of Federal Government R&D activities.

The number of plants installed during the original promotional days of TE is impressive and over 2,000 plants were in operation in 1977 in the United States. However, there has been little unbiased feedback on actual operating costs. The identifications of problems in TE installations has been minimal and R&D efforts could not be formulated. Some general agreement as to the reasons for TE system problems or complete failure do exist; the majority are centered around maintenance costs, inadequacy of controls, auxiliary equipment reliability, and difficulties in expansion to meet growing demands.

1.2 OBJECTIVES OF HUD

One of the goals of the U.S. Department of Housing and Urban Development (HUD) is providing better housing in a suitable living environment at reasonable costs. Space heating, domestic hot water, space cooling, electrical energy for lighting and home appliances are all part of better housing, and clean air and water contribute to a suitable living environment. Each of these items reflect on the better use of resources and the correction of wasteful and expensive practices.

HUD'S evaluation of the TE concept began in 1970. During this same time period, HUD had a large scale program underway to demonstrate industrialized housing. The program was called "Operation BREAKTHROUGH". The BREAKTHROUGH sites were conventionally financed, owned and insured by HUD and developed under contracts with developers and industrialized housing producers. The existence of the BREAKTHROUGH program provided an excellent opportunity for HUD to demonstrate and evaluate innovative utilities including the total energy concept by using the BREAKTHROUGH sites. These sites were eventually sold by HUD to private sector owners, including the TE plant.

1.3 NBS ROLE IN PROJECT

Based on feasibility studies made by NBS and other factors, HUD chose the Jersey City Operation BREAKTHROUGH Site (described subsequently) as the location of the TE demonstration. NBS prepared a performance specification. A contract was awarded to Gamze-Korobkin-Caloger (GKC), an engineering design corporation in Chicago, for complete design and preliminary analysis of the plant.

1.4 TIME FRAME OF CONSTRUCTION TO OPERATION

Construction at the Jersey City site started in November 1971 and the TE plant was put in operation in January 1974. In parallel with the site construction activities, NBS designed and built an instrumentation and data acquisition system (DAS) and proceeded to establish and refine procedures used in the evaluation of the demonstration. The DAS was put in service in April 1975, automatically recording engineering data from the plant. The monitoring instruments in the site buildings were put on-line with the DAS in November 1975. The evaluation for HUD continued through December 1977 and therefore included a total of 33 months of measured DAS data and up to 48 months of economic data.

2. SITE DESCRIPTION

2.1 SITE BUILDINGS

The Jersey City Total Energy site occupies an area of 6.35-acres (2.6-hectares) and contains four apartment buildings, an elementary school, a swimming pool, a commercial building and parking space for the tenants. Figure 2-1 shows an aerial view of the site and its surroundings. Figure 2-2 depicts the plan layout of the individual buildings contained on the site. The four apartment buildings provide 486 dwelling units varying from economy apartments to four bedroom units. Some of the units are two-floor apartments. The individual apartment buildings vary from 7 to 18 stories above ground level and contain from 40 to 152 apartment units. The three-story commercial building contains approximately 25,500 ft^2 (2369 m^2) of rentable office area, 20,500 ft^2 (1905 m^2) of store area, and a 72 space in-building parking area.

The two-story elementary school (Preschool through Grade 3) contains approximately 15,700 ft^2 (1460 m^2). A small outdoor swimming pool is adjacent to the school.

The site buildings are served by a 4-pipe hot and chilled water distribution system from the central total energy plant.

2.2 PLANT

The major components of the TE plant are five diesel engine-generators, two hot water boilers and two absorption-type chillers. The engine generators are shown in figure 2-3. A schematic diagram showing the relative position of the major components in the plant is shown in figure 2-4. The broad line represents the primary hot water (PHW) loop. This is a closed loop with the pumps circulating approximately 11,000 pounds (5000 kg) of water per minute around the loop. The water passes through one or two of the boilers in series depending upon the valving by the plant engineer. The absorption-type chillers utilize hot water from the PHW loop when they are in service. Secondary hot water heat exchangers supply heat from the PHW loop to the secondary distribution system serving the site. The dry cooler and emergency heat exchanger are units in the loop which limit the temperature level in the loop to a maximum of approximately 230°F (110°C). These units prevent the overheating of the engines in the event of a very low demand for hot water from the plant or a control malfunction. The dry cooler releases excessive heat into the atmosphere via forced convection and the emergency heat exchanger releases heat to city water when the emergency valves are opened.

The PHW passes through the jackets of all five engines in parallel. A portion of the water passing through each jacket is routed through a separate exhaust gas heat exchanger supplied for each engine. From these exchangers, the PHW returns to the common loop.

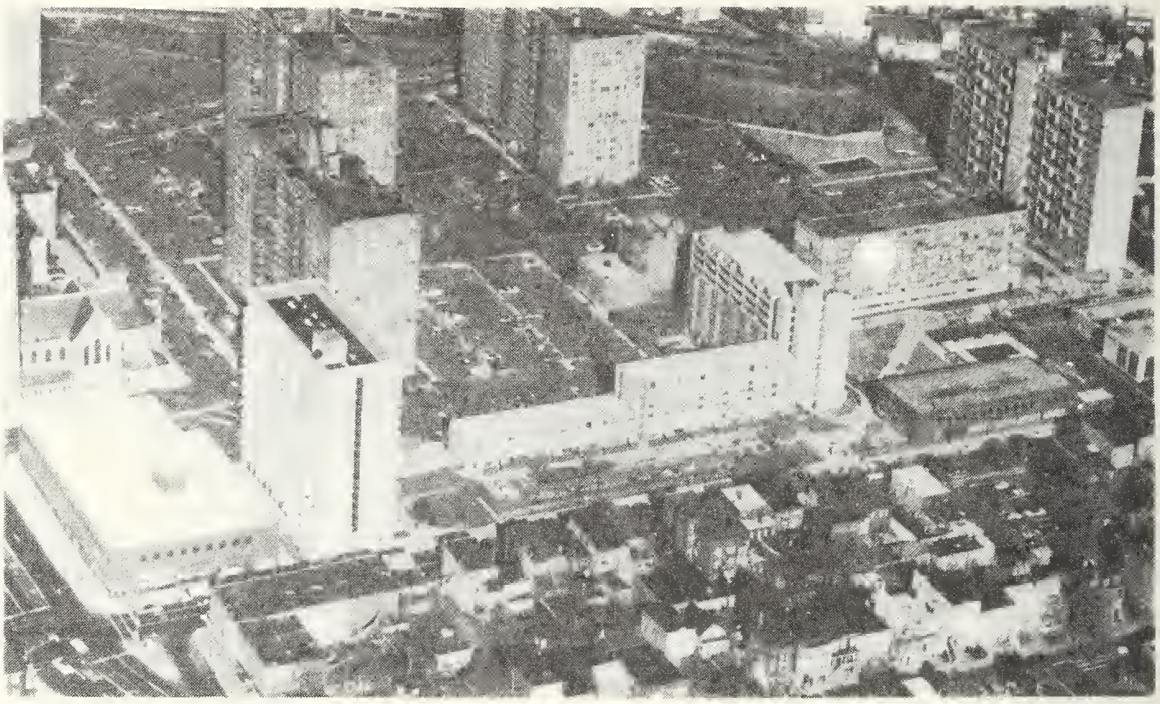

Figure 2-1. Overall view of total energy site

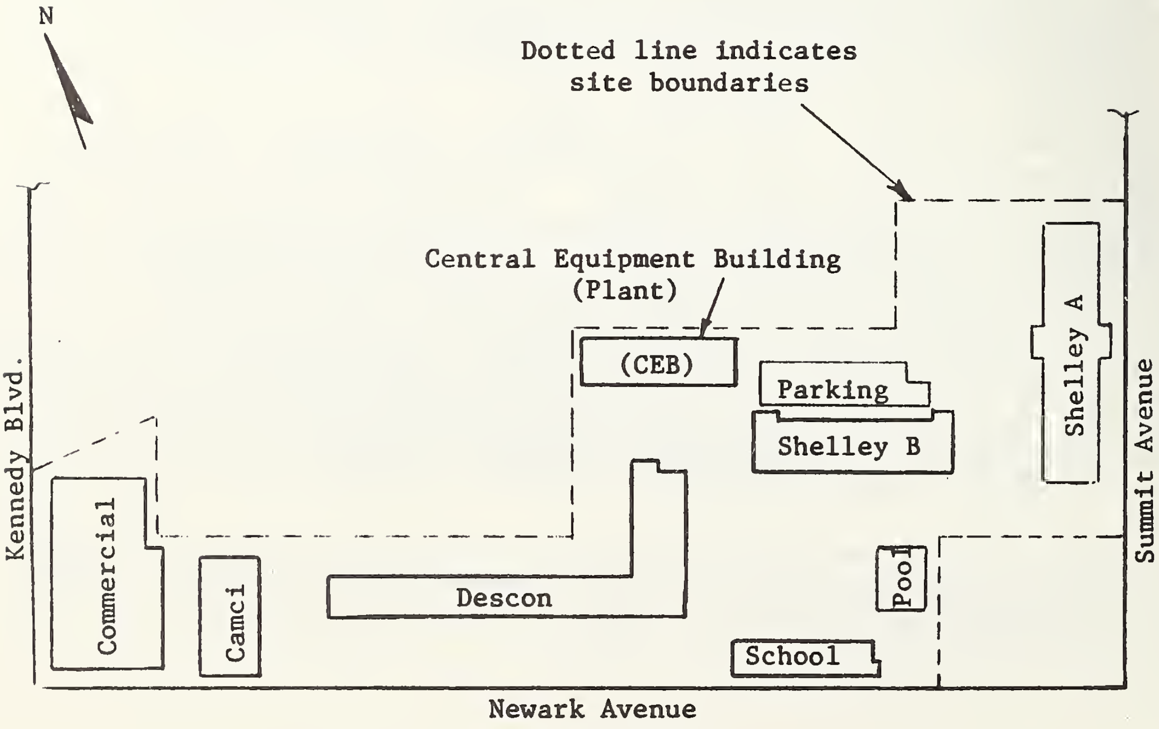

Figure 2-2. Relative location of individual buildings at the Jersey City Total Energy Site

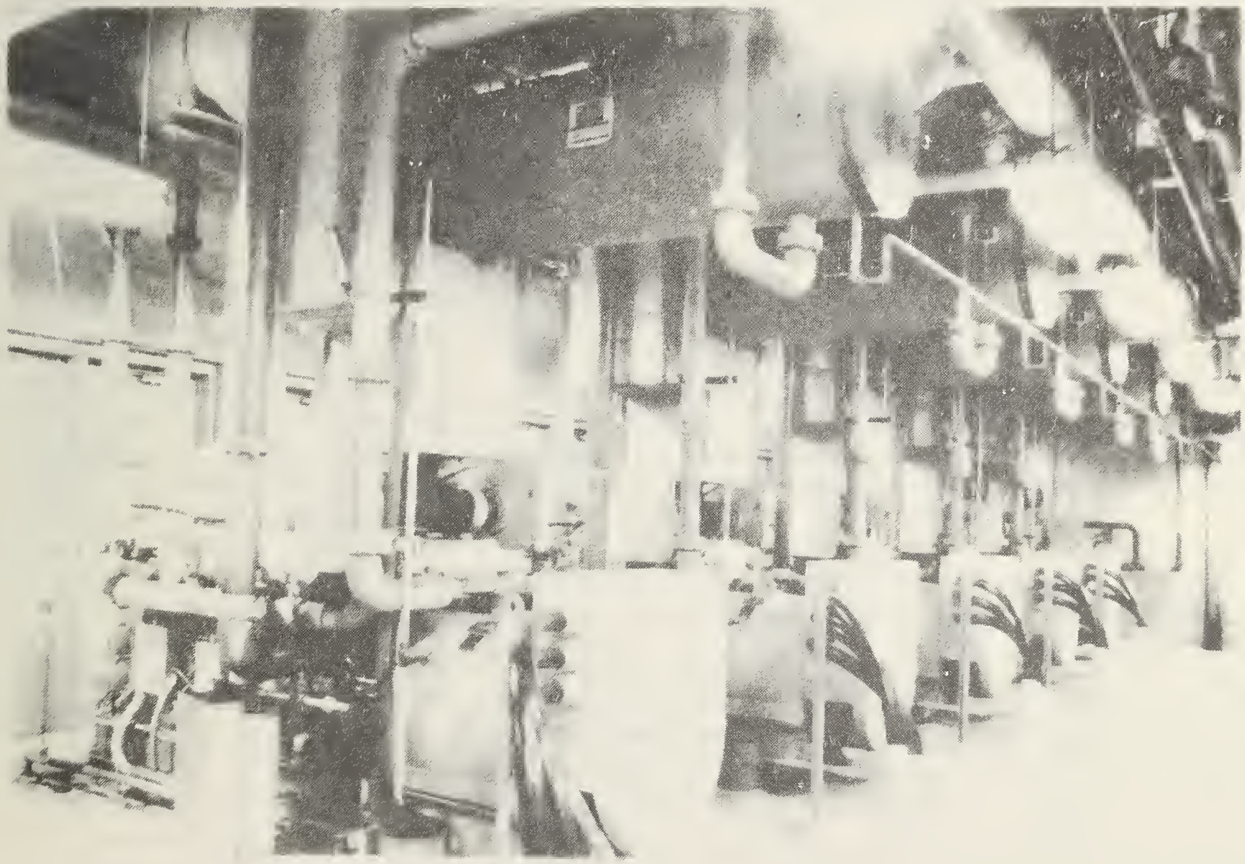

Figure 2-3. The five 600 KW engine-generators

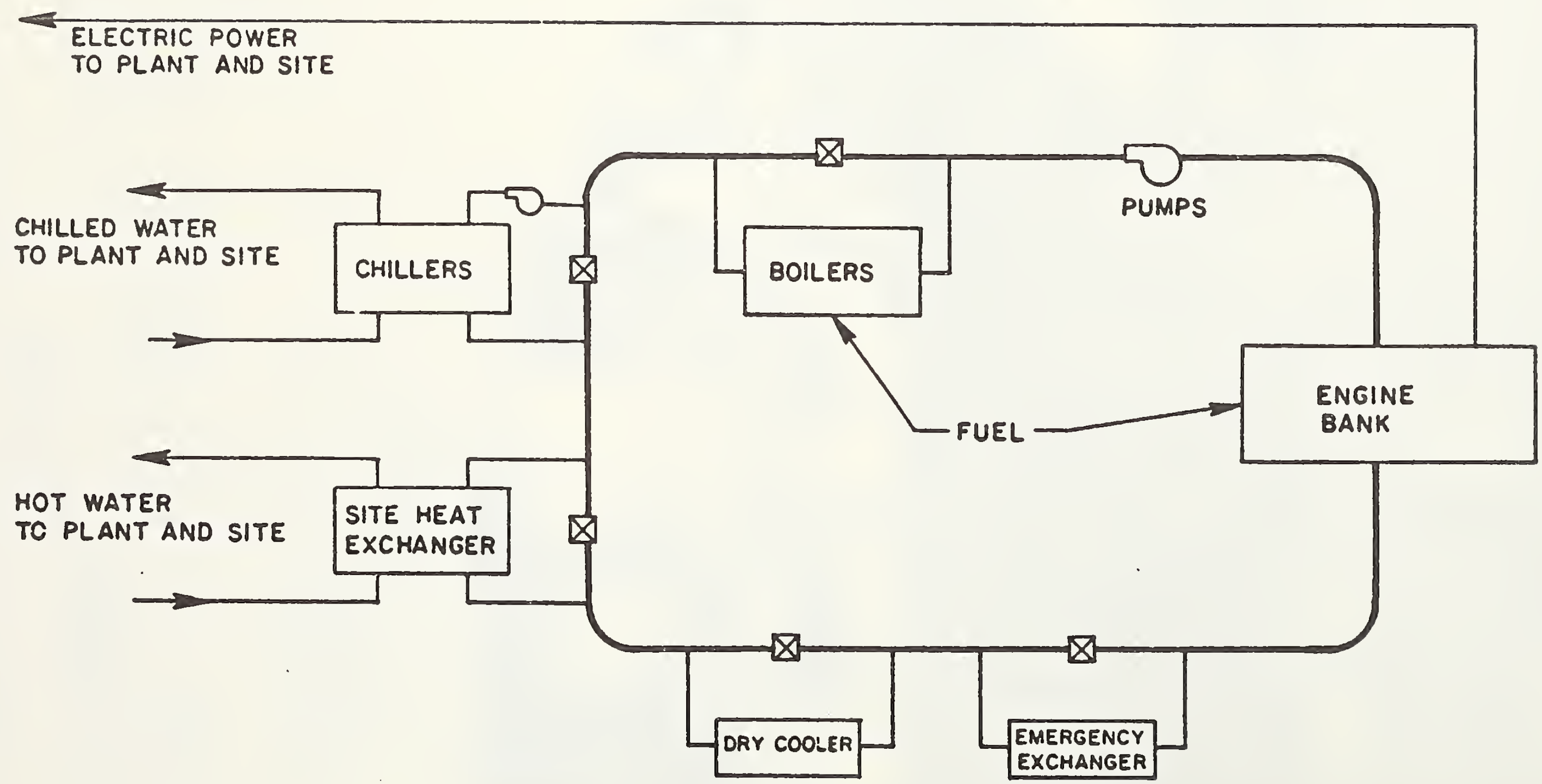

Figure 2-4. Plant primary hot water loop

3. PLANT AND SITE MEASUREMENTS

3.1 OBJECTIVES

Continuous, on-site measurements were the major part of the NBS/JCTE monitoring program. These engineering measurements, their frequency and accuracy, and the duration of the monitoring were determined by the data requirements of the JCTE evaluation activities. These efforts included plant and site energy use studies, plant component performance evaluations and an assessment of the quality of the utility services supplied to the site tenants.

The energy study plan sought to account for all energies supplied to the plant, the energy used by the plant for its operation, the energy supplied to each of the site buildings, the distribution losses, and that energy discarded from the plant as waste heat. These data were used to calculate an overall plant energy effectiveness as a function of time.

3.2 DATA ACQUISITION SYSTEM

The instrumentation and data acquisition system (DAS) monitored approximately 135 plant and 90 site variables at five-minute intervals on a year-round basis. The system recorded these data on magnetic tape for shipment to NBS for processing. A modem link over a telephone line from the DAS to NBS was also available for the transmission of real-time data during the later part of the period covered by this report.

The data recorded by the DAS originated from monitoring transducers located in the plant and in the electrical and mechanical rooms of the site buildings. The transducers and the DAS did not affect the operation of the plant since they were designed and installed to be completely independent of the operational instruments and controls used by the plant operator. The DAS monitoring instrumentation included flowmeters and venturis to measure fuel and water flow rates, thermocouples and multi-junction thermopiles to determine temperatures, Hall-effect meters and related components to measure instantaneous electrical power, pressure cells for pressure measurements and seven types of weather instrumentation. Signal conditioning circuitry was used where necessary and integration techniques were used to convert instantaneous electrical power signals to electrical energy signals. Integration circuitry was also used to provide analog signals from the pulsating output signals.

The central station of the DAS is shown in figure 3-1 and was located in the central equipment building (plant). The central DAS sampled, digitized and recorded on magnetic tape the output of all instrumentation within a 30-second time period. This process was performed every five minutes, 24 hours each day. The reels of magnetic tape from the DAS were sent at about weekly intervals to NBS for processing.

3.3 DATA PROCESSING

The magnetic tapes from the DAS were processed by a computer which converted raw millivolt data to engineering units, using instrumentation calibration data.

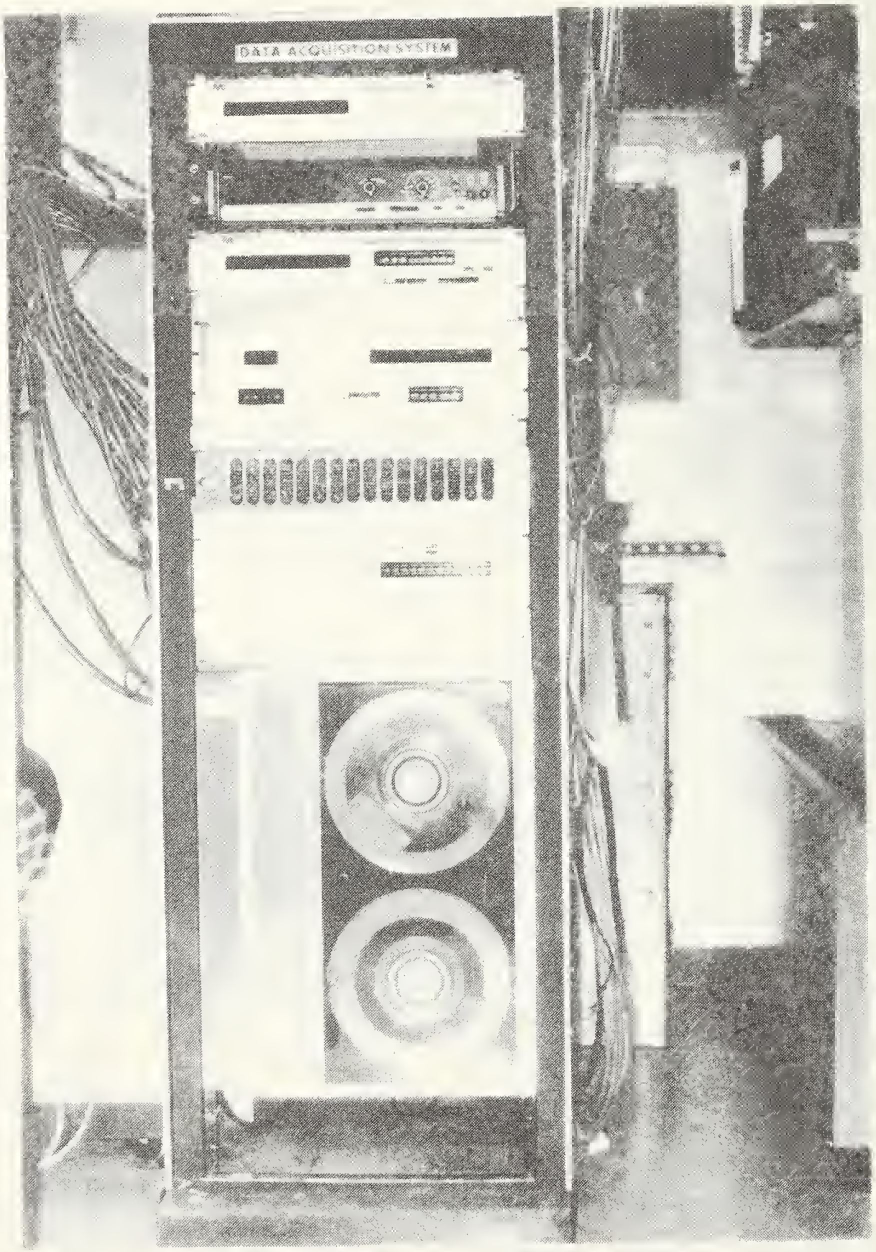

Figure 3-1. The data acquisition system located in the plant

The end result of the computer processing was the conversion of the raw DAS data from each channel into hourly engineering data and approximately 320 derived variables stored on monthly magnetic storage discs.

3.4 ACCURACY OF DATA

The accuracy of the engineering data presented is primarily dependent upon the accuracy of the measurement instrumentation. In general, the DAS instrumentation installed at the JCTE site was capable of producing data at acceptable levels of accuracy for heat balance calculations, load patterns, mathematical models, etc. The accuracy of engineering values computed from more than one DAS channel depends on the combined accuracy of the individual pieces of instrumentation.

Special factors which reflect on the accuracy of the data presented include the percentage of time in the period of interest that raw data were recorded. Figure 3-2 presents a bar graph representing the percentage of time the DAS was producing valid engineering data for each month of the 33-month period covered in this report.

Other factors which reflect on the accuracy include the use of small differences in temperature to determine certain derived variables. The error increases as the temperature difference between two points decreases. The reader interested in further details of the accuracy of the values presented in this executive summary is referred to the Final Report and related references given.

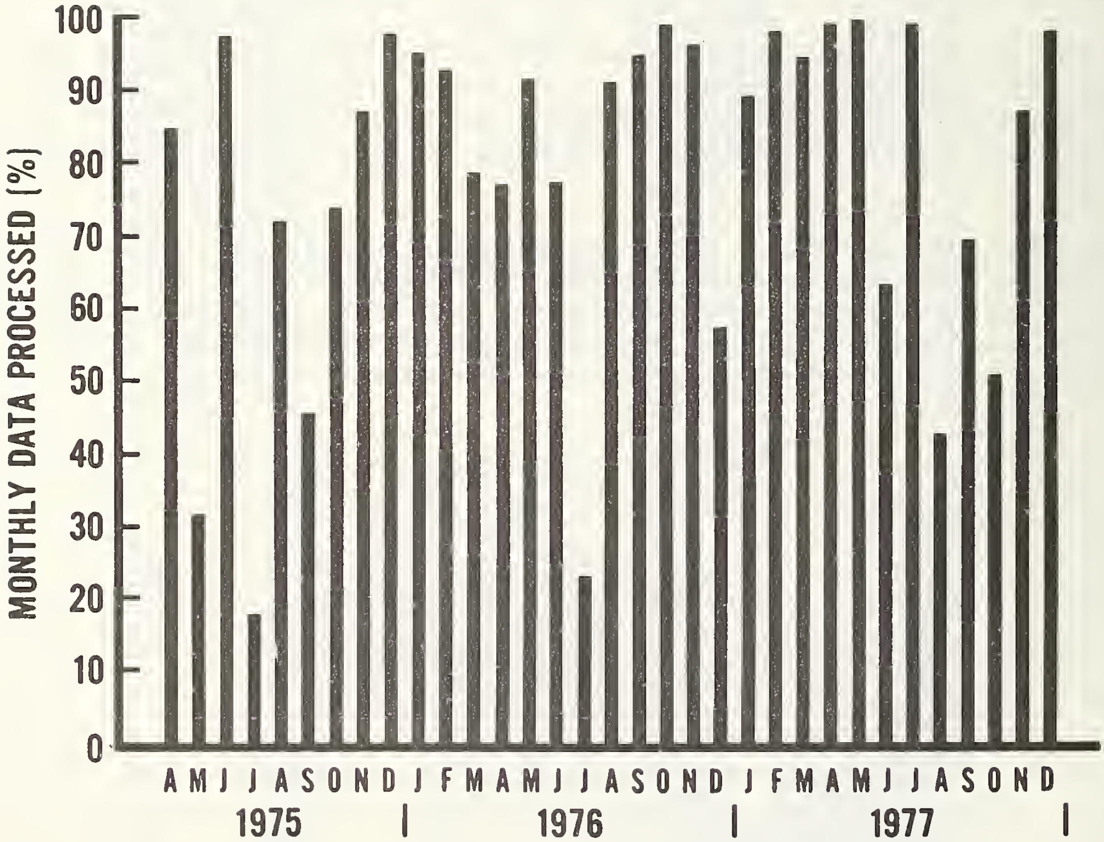

Figure 3-2. Percentage of time in the month when data were recorded and processed by NBS

4. ENGINEERING DATA - PLANT AND SITE BUILDINGS

This section of the executive summary presents engineering data for the plant and site buildings. The reader is encouraged to refer to the Final Report before using these data for comparison or modelling purposes.

4.1 THERMAL AND ELECTRICAL MEASUREMENTS FROM PLANT

Figure 4-1 is a schematic diagram of the PHW loop which has been simplified to indicate the basic thermal energy inputs and outputs of the plant. These values are listed in table 4-1. The reader is referred to the Final Report for more detailed definitions of the terms used in all tables presented in this section. Figures 4-2 and 4-3 represent daily thermal outputs of the boiler and engines, and the output of the chillers, respectively, for the 1977 season.

Table 4-2 presents the monthly values of electrical energy (kilowatt-hours) recorded by the DAS. The important items in this table are: (1) the gross electrical energy generated, (2) the site load (the total supplied to the site buildings) and (3) the "net generated" which is equivalent to the electrical energy the plant and site would be purchasing from the local utility if the plant were not generating electrical power.

Table 4-3 lists the monthly fuel consumption of the boiler and engines, the higher heating value of the fuel, the number of boilers on-line and the heating and cooling degree-days for each of the 33 months.

Table 4-4 presents the monthly component and plant performance values. The "engine gross electrical efficiency" is the gross output of the generators divided by the higher heating value (HHV) of the fuel consumed by the engines. The "engine gross electrical plus thermal efficiency" is the sum of the gross electrical output of the generators and the thermal energy recovered from the engines divided by the HHV of the fuel consumed by the engines. The "boiler efficiency" is the thermal input to the PHW loop by the boilers divided by the HHV of the fuel consumed by the boilers. The "chiller COP" is the thermal output of the chillers divided by the thermal input from the PHW loop to the chillers. The COP does not include the electrical energy required to operate the auxilliary pumps for the chillers. The "engine-generator heat rate" is the HHV of the fuel required to produce one kWh of net electrical energy. These values are listed for comparison with the typical values listed by electric utilities. The "plant energy effectiveness" values were calculated considering the plant as a "black box" and dividing the thermal and electrical outputs of the plant (electrical, heating and cooling) by the HHV of the total fuel consumed by the plant. These values are listed to compare the operation of the JCTE plant on a seasonal basis and are not valid for direct comparison with other plants utilizing different types of chillers or for plants located in climates significantly different from the JCTE site.

4.2 THERMAL AND ELECTRICAL LOAD DATA FOR SITE BUILDINGS

An additional task of the JCTE project was to collect data from the individual site buildings to determine the electrical, heating, domestic hot water, and cooling loads. The remote DAS units were put in service in November 1975.

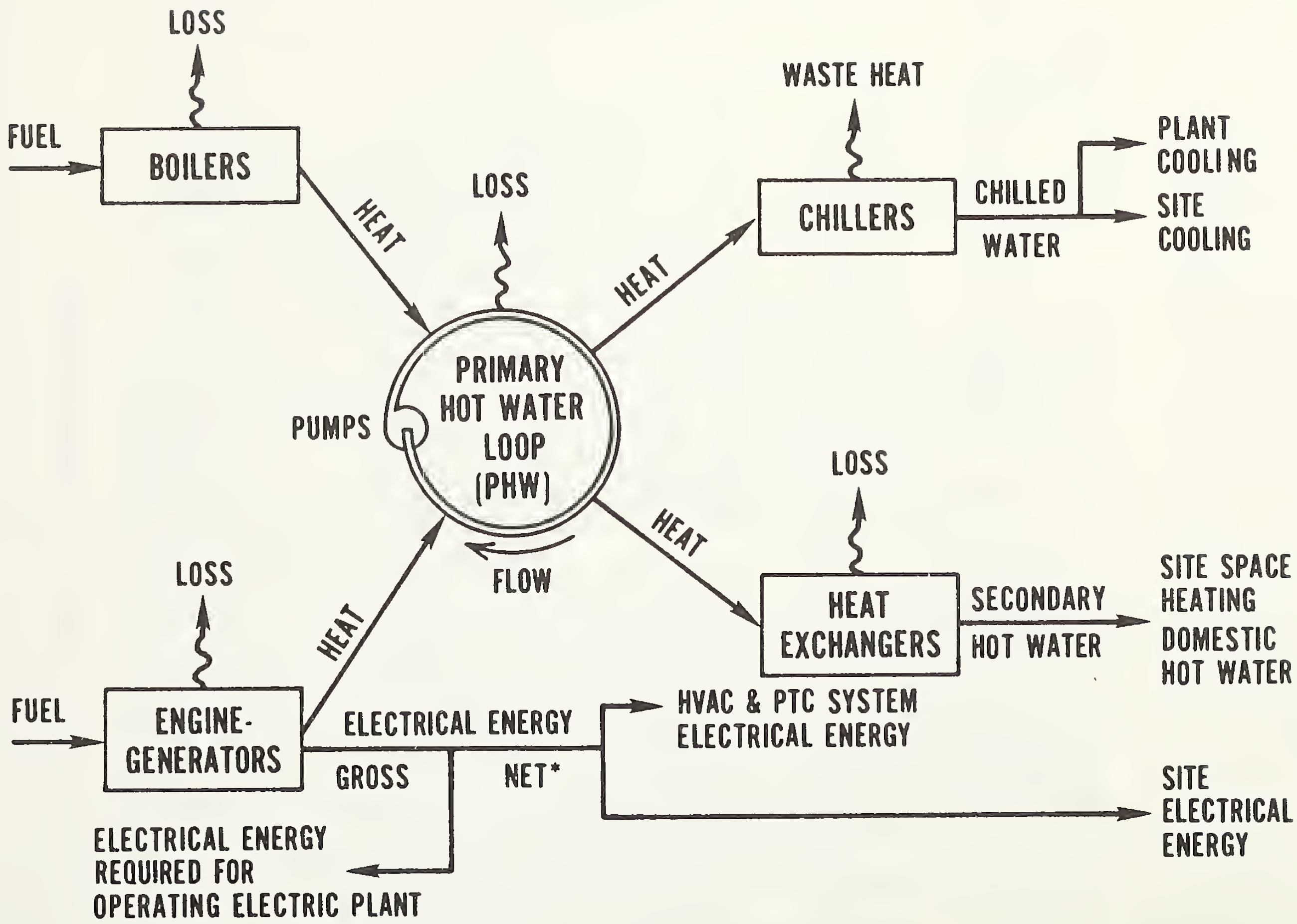

Figure 4-1. Major energy flow diagram of plant

* Electrical energy required if purchased from local utility

Table 4-1. Monthly thermal data (millions of Btu)

Month	Recovered from engines	Recovered from boilers	PHW heat to chillers	PHW heat to secondary HW exchangers	PHW dry cooler and piping losses	cooling loads plant	cooling loads site
1975							
April	1728	3075	0	4096	707	0	0
May	1744	1471	760	1884	571	0	100
June	2198	3891	3488	904	1697	336	1000
July	2428	2631	4020	800	239	356	1804
August	2556	3888	5357	802	285	468	2133
September	1839	1087	783	1003	1140	84	128
October	1751	1062	0	2266	547	0	0
November	1863	1986	0	3362	487	0	0
December	2028	4144	0	5544	628	0	0
1976							
January	1753	5635	0	6904	484	0	0
February	1797	3825	0	5158	464	0	0
March	1922	2897	0	4421	398	0	0
April	1930	1252	0	2867	315	0	0
May	1994	559	396	1766	391	1	87
June	2433	4622	5233	1155	667	297	1864
July	2592	4469	5760	1084	217	396	2294
August	2641	5666	6937	1091	279	412	2334
September	2613	3575	4763	1130	395	268	1285
October	2011	1724	313	2957	465	33	140
November	1981	3229	0	4737	473	0	0
December	2001	5032	0	6520	513	0	0
Total 1976	25668	42485	23402	39790	5061	1407	8004
1977							
January	2184	6038	0	7630	592	0	0
February	1798	4023	0	5391	430	0	0
March	1935	2566	0	4128	373	0	0
April	1920	1301	0	2891	330	0	0
May	2096	1540	1606	1765	265	101	490
June	2234	2394	3264	1138	226	254	1366
July	2656	3856	5378	890	244	398	2679
August	2524	3855	5210	985	184	460	2452
September	2216	3747	4525	1144	294	350	1263
October	1953	1536	314	2744	431	38	83
November	1867	2865	0	4236	496	0	0
December	2066	4925	0	6453	538	0	0
Total 1977	25449	38646	20297	39395	4403	1601	8333

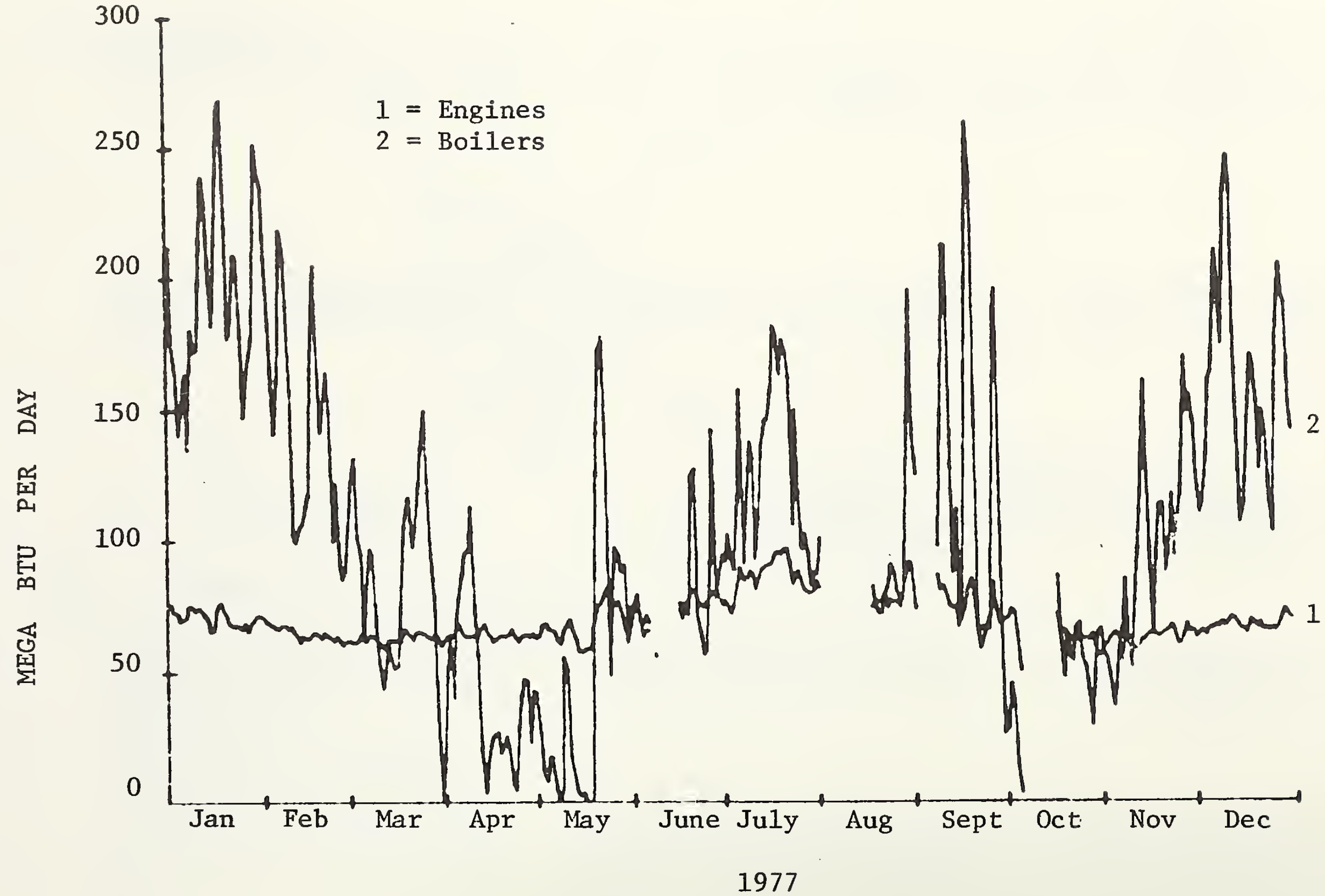

Figure 4-2. Thermal energy recovered from engines and boilers

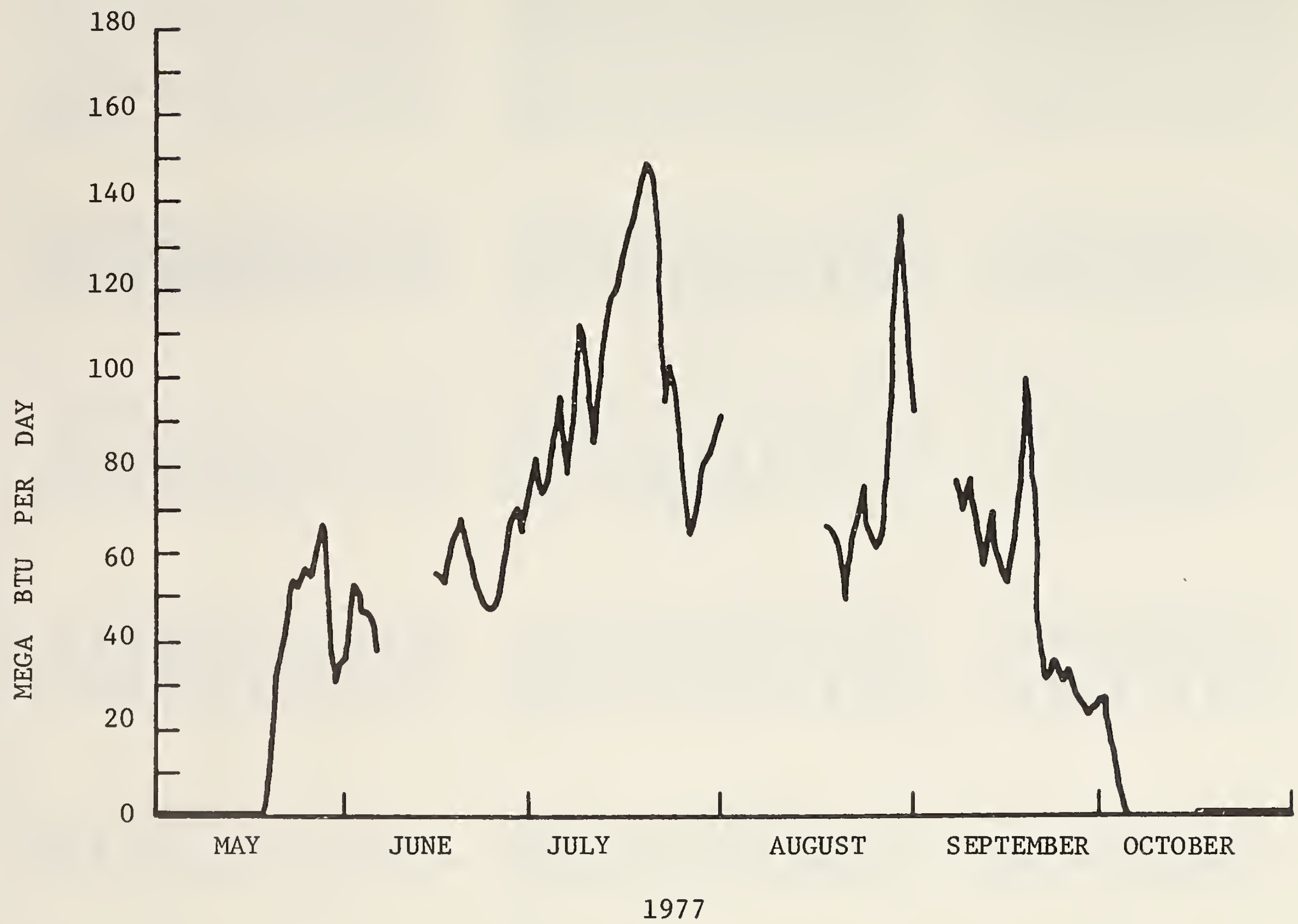

Figure 4-3. Output of absorption chillers at plant

Table 4-2. Monthly electrical data (Megawatt-hours)

Month	Gross generated	Allocated to heating	Allocated to cooling	Total allocated to HVAC in-plant	PTC* load	Site load	Net generated
1975							
April	531.5	55.7	0	55.7	6.7	403.2	465.6
May	542.2	43.8	14.3	58.1	3.8	416.3	478.2
June	638.5	26.0	150.3	176.3	3.5	459.8	640.4
July	740.3	27.5	175.6	203.1	3.2	487.1	693.4
August	758.0	28.7	179.1	207.7	3.2	498.1	709.0
September	637.4	41.8	42.4	84.4	3.8	466.9	555.1
October	576.9	46.5	0	46.5	3.1	465.0	514.6
November	593.5	52.2	0	52.2	2.5	495.2	550.9
December	652.1	55.4	0	55.4	2.7	541.2	599.3
1976							
January	674.9	57.8	0	57.8	2.9	557.0	617.8
February	621.2	52.2	0	52.2	2.4	506.6	561.2
March	650.6	56.6	0	56.6	6.1	523.2	585.9
April	607.0	47.3	0	47.3	7.6	478.4	533.3
May	634.0	39.0	22.8	61.8	8.4	482.1	552.2
June	790.7	28.2	152.6	180.8	4.9	542.4	728.4
July	822.8	29.3	179.2	208.5	3.5	565.8	776.8
August	850.2	31.0	200.6	231.6	3.0	567.5	802.1
September	809.5	29.0	182.3	211.3	3.1	544.4	758.8
October	662.4	49.3	15.2	64.4	3.1	530.2	597.7
November	639.3	56.2	0	56.2	3.4	523.2	582.7
December	676.4	56.9	0	56.9	3.9	558.1	618.9
Total 1976	8439.0	532.8	752.7	1285.4	52.3	6378.9	7715.8
1977							
January	689.8	55.6	0	55.6	3.1	574.6	633.3
February	607.8	48.9	0	48.9	2.8	501.9	553.6
March	641.1	53.4	0	53.4	3.3	520.8	577.5
April	617.2	46.7	0	46.7	3.2	499.0	548.9
May	664.4	35.8	63.9	99.6	4.0	494.3	597.9
June	723.9	26.6	134.4	161.0	3.4	510.3	674.7
July	834.6	30.8	178.1	208.9	3.4	570.0	782.2
August	821.7	29.5	156.5	186.0	3.7	580.5	770.2
September	739.3	25.5	140.9	166.3	3.3	522.3	691.9
October	630.4	44.6	19.4	64.9	4.0	499.8	568.7
November	606.2	55.1	0	55.1	4.5	498.3	555.0
December	662.7	56.8	0	56.8	3.5	547.9	608.2
Total 1977	8239.1	509.3	693.2	1203.2	42.2	6319.7	7562.1

* PTC - Pneumatic Trash Collection

Table 4-3. Monthly fuel data

Month	Consumed by engines (gallons)	Consumed by boilers (gallons)	Total fuel consumed (gallons)	Higher heating value (Btu per gallon)	No. of boilers on-line	Degree-days Heating	Degree-days Cooling
1975							
April*	40,652	27,490	68,142	139,400	2	524	0
May*	41,470	13,833	55,303	139,400	2	84	117
June*	52,061	34,316	86,378	139,580	2	6	211
July*	56,143	23,537	79,680	140,600	2	0	375
August*	57,485	34,180	91,665	140,600	2	1	321
September*	48,335	10,423	58,758	140,600	2	59	46
October*	44,352	10,392	54,744	138,703	2	195	20
November*	45,786	18,348	64,134	138,200	2	400	10
December*	49,938	36,706	86,644	139,226	2	913	0
1976							
January*	51,623	49,394	101,017	139,400	2	1170	0
February*	47,369	33,752	81,121	139,824	2	738	0
March*	49,552	25,900	75,451	140,000	2	645	0
April*	46,227	11,871	58,098	140,000	2	338	50
May	48,361	5,455	53,816	138,970	1.5	141	30
June	60,267	41,505	101,772	138,440	1	17	281
July	62,824	36,794	99,618	138,665	1	0	317
August	64,586	47,618	112,204	138,890	1	4	305
September	61,906	29,450	91,356	138,967	1	56	110
October*	50,749	15,384	66,133	139,168	1	381	6
November	49,532	25,937	75,469	139,665	1	745	0
December	51,927	40,835	92,762	139,500	1.7	1107	0
Total 1976	644,923	363,895	1,008,817			5342	1099
1977							
January	52,010	50,531	102,541	139,060	2	1361	0
February	46,220	32,923	79,143	139,096	2	895	0
March	49,807	20,722	70,529	139,000	2	563	6
April	47,788	10,816	58,604	139,400	2	352	18
May	51,407	13,663	65,070	138,935	1.3	89	111
June	54,703	20,022	74,726	138,320	1	24	191
July	63,171	34,623	97,794	139,355	1	0	414
August	62,463	33,506	95,969	139,640	1	0	321
September	56,745	30,830	87,575	139,640	1.5	50	146
October	47,791	14,836	62,627	139,640	2	319	1
November	46,936	26,367	73,303	139,000	2	527	0
December	50,653	43,530	94,183	139,000	2	975	0
Total 1977	629,694	332,369	962,064			5155	1208

* Fuel consumption data based on 32 percent engine-generator efficiency and boiler model

Table 4-4. Monthly component and plant performance

Month	Engine gross electrical efficiency %	Engine gross electrical plus thermal efficiency %	Boiler efficiency %	Chiller COP	Engine-gen. heat rate (Btu per net kWh)	Plant energy effectiveness
1975						
April*	32.0%	62.5%	80.2%	-	12,170	57.6%
May*	32.0%	62.2%	76.3%	.132	12,090	44.2%
June*	32.0%	62.3%	81.2%	.383	11,347	28.8%
July*	32.0%	62.8%	79.5%	.537	11,383	38.1%
August*	32.0%	63.6%	80.9%	.486	11,399	36.1%
September*	32.0%	59.1%	74.2%	.271	12,243	33.0%
October*	32.0%	60.5%	73.7%	-	11,954	50.7%
November*	32.0%	61.4%	78.3%	-	11,487	57.0%
December*	32.0%	61.2%	81.1%	-	11,602	61.3%
1976						
January*	32.0%	56.4%	81.8%	-	11,649	62.6%
February*	32.0%	59.1%	81.0%	-	11,803	60.8%
March*	32.0%	59.7%	79.9%	-	11,841	58.6%
April*	32.0%	61.8%	75.3%	-	12,136	55.3%
May	32.2%	61.9%	73.7%	.245	12,171	46.6%
June	32.3%	60.3%	80.4%	.413	11,454	34.5%
July	32.2%	62.0%	87.6%	.467	11,214	38.4%
August	32.3%	61.8%	85.7%	.396	11,184	34.6%
September	32.1%	62.5%	87.4%	.326	11,338	33.6%
October*	32.0%	60.5%	80.5%	.553	11,816	53.3%
November	31.5%	60.2%	89.1%	-	11,872	61.9%
December	31.8%	59.5%	88.3%	-	11,703	65.1%
1977						
January	32.5%	62.7%	85.9%	-	11,420	67.2%
February	32.3%	60.2%	87.8%	-	12,048	64.5%
March	31.6%	59.5%	89.1%	-	11,988	60.2%
April	31.7%	60.4%	86.3%	-	12,136	56.2%
May	31.7%	61.1%	81.1%	.368	11,945	43.6%
June	32.6%	62.2%	86.4%	.496	11,214	41.1%
July	32.3%	62.5%	79.9%	.572	11,254	40.5%
August	32.1%	61.1%	82.4%	.559	11,325	40.4%
September	31.8%	59.8%	87.0%	.356	11,452	34.3%
October	32.2%	61.5%	74.1%	.385	11,734	51.8%
November	31.7%	60.3%	78.2%	-	11,755	60.2%
December	32.1%	61.5%	81.4%	-	11,576	63.6%

* Values based on 32.0 percent engine-generator efficiency and boiler model.

4.2.1 Thermal Loads of Site Buildings

Tables 4-5, 4-6 and 4-7 list the thermal energy consumed by the site buildings in the East and West distribution loops. Unscheduled changes in building circulation pump capacities and delays in deliveries of replacement differential pressure cells to accommodate the flow increase or decrease through the venturis were the primary causes for the excessive loss of valid data.

4.2.2 Electrical Loads of Site Buildings

The electrical loads for the site buildings are presented in a limited form in this section. The original instrumentation installed in three of the six site buildings by the contractor was inadequate to present valid data for actual electrical energy consumption. Please refer to Final Report for details.

Three buildings for which valid data were produced were Shelley B, the commercial building, and the school. The available data indicated that the school consumed less than 3% of the total site electrical energy and are not tabulated. Table 4-8 lists the monthly electrical data for the Shelley B and commercial building. Seasonal diurnal profiles for these buildings are presented in figures 4-4 and 4-5. These profiles are of interest in comparing seasonal loads and in indicating the relatively high load factors. The profile of the commercial building was made for the weekdays Wednesday, Thursday, Friday and Saturday. The lower weekend loads are apparent.

The table and the profiles of the individual building electrical loads are labeled PE and PN, denoting the loads of the "essential" bus and the "normal" bus. The essential bus loads include hall and stairway lighting, water pumps, one elevator per building, and any other items deemed necessary by the local code in the event of a failure of the electrical output from the plant. During plant outages, these loads and the essential loads of the plant were automatically switched to the local utility power lines. As soon as the plant was put back in service, these loads were returned to the essential lines from the plant. The reliability of the electrical plant will be discussed subsequently.

Table 4-5. Monthly thermal data for site buildings on East Secondary hot water circulation loop (millions of Btu)

	Shelley "A"			Shelley "B"			School		
Month	Domestic hot water	Space heating	Total	Domestic hot water	Space heating	Total	Domestic hot water	Space heating	Total
1975									
November	363	555	918	100	368	468	.6	NA	NA
December	NA	NA	NA	109	458	567	.6	NA	NA
1976									
January	470	1290	1760	129	670	689	.6	NA	NA
February	419	873	1292	104	328	432	.6	NA	NA
March	404	750	1154	88	327	415	.6	NA	NA
April	314	653	967	57	184	241	.6	NA	NA
May	349	376	725	98	NA	NA	.6	NA	NA
June	322	0	322	90	0	90	.5	0	.5
July	277	0	277	88	0	88	.5	0	.5
August	260	0	260	87	0	87	.5	0	.5
September	257	0	257	80	0	80	.6	0	.6
October	288	NA	NA	82	237	319	.6	80	80.6
November	395	NA	NA	101	401	502	.6	160	161
December	448	NA	NA	113	NA	NA	.6	222	223
1977									
January	421	1492	1913	120	527	647	.6	234	235
February	345	NA	NA	112	NA	NA	.6	197	198
March	394	NA	NA	124	705	829	.6	104	105
April	322	NA	NA	117	247	364	.6	62	63
May	330	NA	NA	106	61	167	.6	11	12
June	305	0	305	91	0	91	.5	0	.5
July	237	0	237	75	0	75	.5	0	.5
August	NA	0	NA	NA	0	NA	.5	0	.5
September	132	0	132	NA	0	NA	.5	0	.5
October	NA	NA	NA	129	173	302	NA	NA	NA
November	286	853	1139	112	284	396	NA	NA	NA
December	354	1410	1764	121	492	613	NA	NA	NA

NA = Data not available

Table 4-6. Monthly thermal data for site buildings on West Secondary hot water circulation loop (millions of Btu)

	Descon			Camci			Commercial building		
Month	Domestic hot water	Space heating	Total	Domestic hot water	Space heating	Total	Domestic hot water	Space heating	Total
1975									
November	156	364	520	219	454	673	NA	NA	NA
December	185	700	885	213	786	999	NA	NA	NA
1976									
January	204	745	949	248	1173	1421	NA	NA	NA
February	179	523	702	225	648	873	1	537	538
March	172	455	627	233	576	809	1	475	476
April	163	271	434	240	339	579	1	247	248
May	178	126	304	193	97	290	1	NA	NA
June	169	0	169	158	0	158	1	0	1
July	112	0	112	158	0	158	1	0	1
August	138	0	138	110	0	110	1	0	1
September	111	0	111	139	0	139	1	0	1
October	132	323	455	181	397	578	1	270	271
November	152	487	639	239	648	887	1	445	446
December	159	643	802	299	905	1204	1	564	565
1977									
January	175	780	955	268	1220	1488	1	623	624
February	148	722	870	240	NA	NA	1	NA	NA
March	161	576	737	272	437	709	1	322	323
April	139	292	431	253	291	544	1	225	226
May	123	69	192	266	53	319	1	173	174
June	109	0	109	253	0	253	1	0	1
July	102	0	102	251	0	251	1	0	1
August	NA	0	NA	NA	0	NA	1	0	1
September	165	0	165	NA	0	NA	1	0	1
October	120	350	470	NA	NA	NA	1	142	143
November	103	602	705	173	730	903	1	298	299
December	153	1061	1214	233	1126	1359	NA	NA	NA

NA = Data not available

Table 4-7. Monthly chilled water energy use (millions of Btu)

Month	Shelley A	Shelley B	School	Plant Cooling coil	Plant Fan coil units	Descon	Camci	Commercial building
1976								
May	NA	NA	NA	10	0	NA	NA	NA
June	NA	161	NA	297	20	295	NA	
July	NA	199	NA	396	20	358	107	
August	NA	206	NA	401	11	308	373	417
September	NA	65	50	238	30	129	116	340
1977								
May	NA	NA	NA	NA	NA	NA	NA	NA
June	NA	142	46	219	36	191	249	308
July	NA	251	60	358	40	313	577	383
August	NA	NA	NA	346	34	NA	NA	NA
September	NA	NA	NA	317	33	976	NA	NA
October	NA	NA	NA	32	6	NA	NA	NA

NA = Data not available

Table 4-8. Monthly electrical data for site buildings - Shelley B and Commercial Building (kilowatt - hours)

	Shelley B			Commercial building		
Month	PE	PN	Total	PE	PN	Total
1975						
November	5145	51185	56330	NA	NA	NA
December	5320	58084	63404	NA	NA	NA
1976						
January	5748	60186	65934	2399	43261	45660
February	5386	54711	60097	2157	42739	44896
March	5318	55178	60496	2256	47787	50043
April	5117	50557	55674	2186	45751	47937
May	5152	50397	55549	2228	48235	50463
June	5003	52662	57665	2272	45889	48161
July	5239	53492	58731	2272	53512	55784
August	5244	50807	56051	2203	52785	54961
September	NA	NA	NA	2207	51131	53388
October	5188	55279	60467	2390	48770	51160
November	5237	56844	62081	2378	46525	48903
December	6608	62623	69231	2248	46974	49192
1977						
January	6263	63785	70048	2145	47913	50058
February	5442	57213	62655	2010	44997	47007
March	5614	58083	63697	2360	47365	49725
April	5258	53178	58436	2380	48726	51106
May	5189	49428	54617	2455	52064	54519
June	4807	48874	53681	1911	52167	54078
July	4931	41099	46030	1904	55491	57395
August	NA	NA	NA	NA	NA	NA
September	NA	NA	NA	NA	NA	NA
October	5422	51040	56462	1777	49418	51195
November	5108	53231	58339	1625	48055	49680
December	5528	58364	63892	NA	NA	NA

NA = Data not available
PN = Normal bus
PE = Essential bus

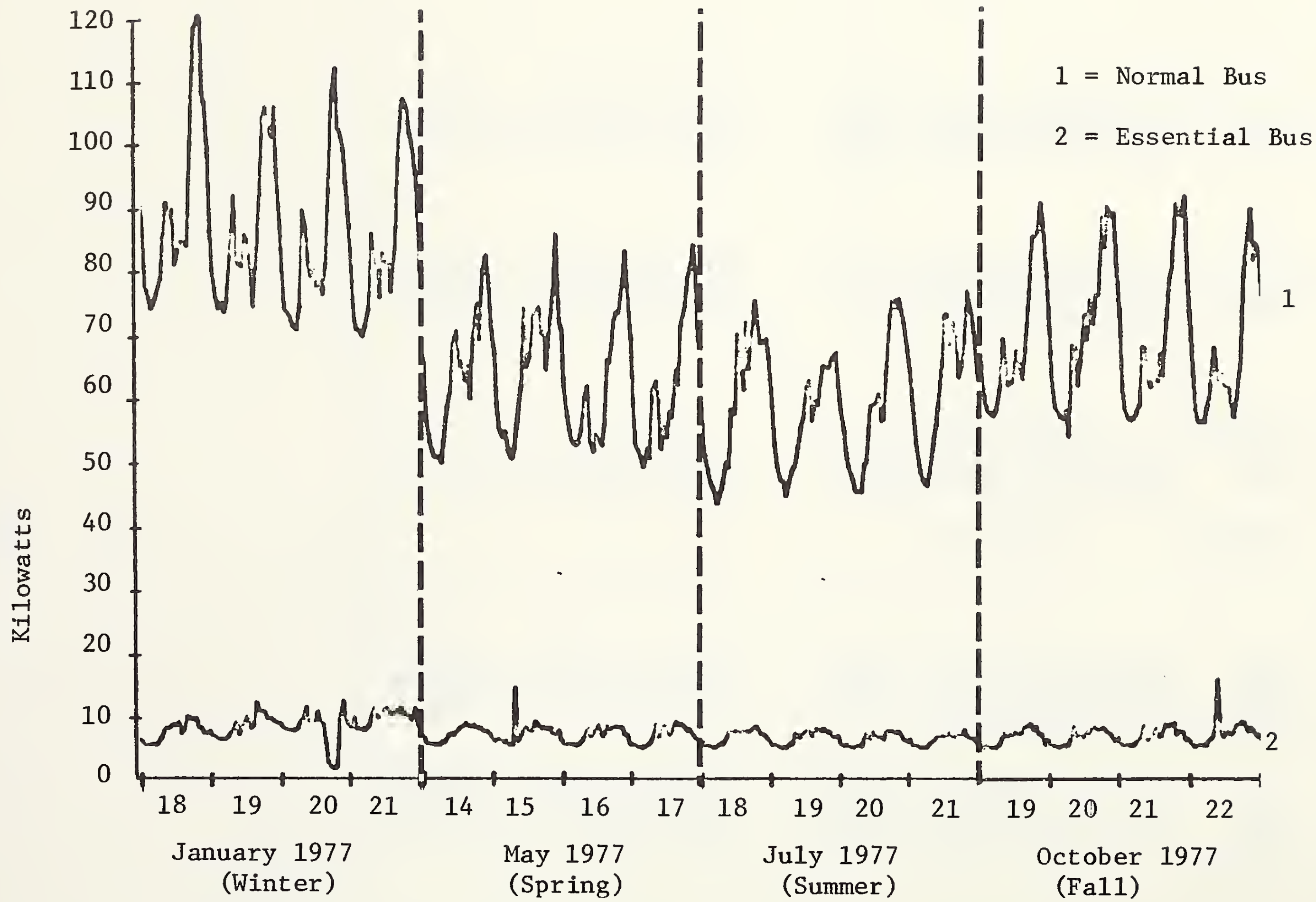

Figure 4-4. Seasonal profiles of electrical loads of Shelley B, residential building

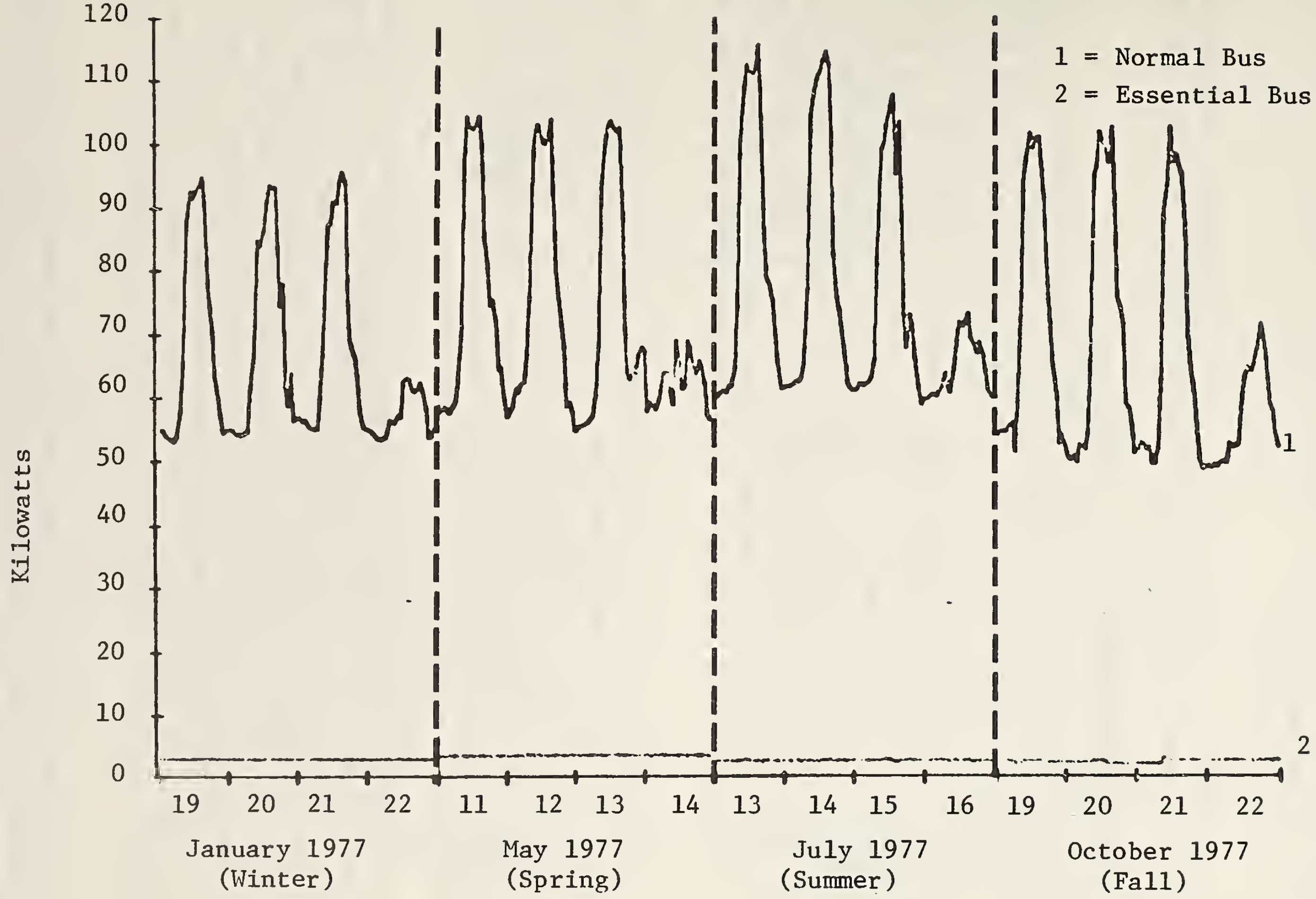

Figure 4-5. Seasonal profiles of electrical loads of the commercial building

5. ENGINEERING ANALYSIS - PLANT COMPONENTS AND SUBSYSTEMS

This section is a synopsis of a series of analyses made of the flow of energy through the Summit Plaza Plant and its major components and subsystems for the 33-month period covered by the DAS engineering data. Emphasis is placed on the last 12 months of this period since they are the most representative of full occupancy of the site buildings.

The reader is referred to the Final Report for a more detailed engineering analysis including possible energy-conserving alternative system configurations.

5.1 ENGINE-GENERATOR PERFORMANCE

The average monthly electrical efficiency of the engine-generators for 1977 was 32.1 percent which is slightly higher than the value of 31.2 percent reported in the factory tests of the units prior to installation in the plant. In addition to maintaining a good electrical efficiency, one of the major factors determining the successful operation of a total energy plant is the recovery and utilization of the thermal energy normally rejected by the engines or other prime movers driving the generators. In general, only about 60 percent of the energy input to the engines was being recovered by electrical and thermal means. An analysis of the available data relating to thermal energy losses in the engine-generators indicated three major losses: (1) thermal losses from the idle engines; (2) thermal losses caused by the accumulation of deposits in the exhaust heat exchangers; and (3) the operation of the engines at low loads.

Figure 5-1 represents the thermal output of engine number 2 in three basic modes of operation: (1) the engine on-line and producing electrical and thermal outputs, (2) the engine not running but remaining in the primary hot water (PHW) loop and (3) the engine valved out of the PHW loop for minor repairs. The thermal output of the engine jacket and exhaust heat exchanger are positive for the engine operating under load, negative for the idle engine in the PHW loop, and zero for the engine valved out of the loop.

The losses from deposits in the heat exchangers are reflected in the rapid increase of the temperature of the output gases after the unit was cleaned as shown in figure 5-2. An analysis of the daily heat recovery from the bank of five engines for the month of January 1978 indicated that the thermal output of the bank of engines was 7.6 percent greater than the electrical output with the exhaust heat exchangers of the engines on-line having two days or less of service after cleaning and 8.6 percent less than the electrical output with the exhaust heat exchangers of the engine on-line having from 13 to 27 days of service of cleaning. The daily profile for the month of January 1978 is shown in figure 5-3.

With the exception of a period of less than the two months, the plant was operated continuously with three engines on-line. The plant operator had elected to derate the capacity of the engine-generator units from 600 kW to 480 kW, allowing 120 kW for "transient loads".

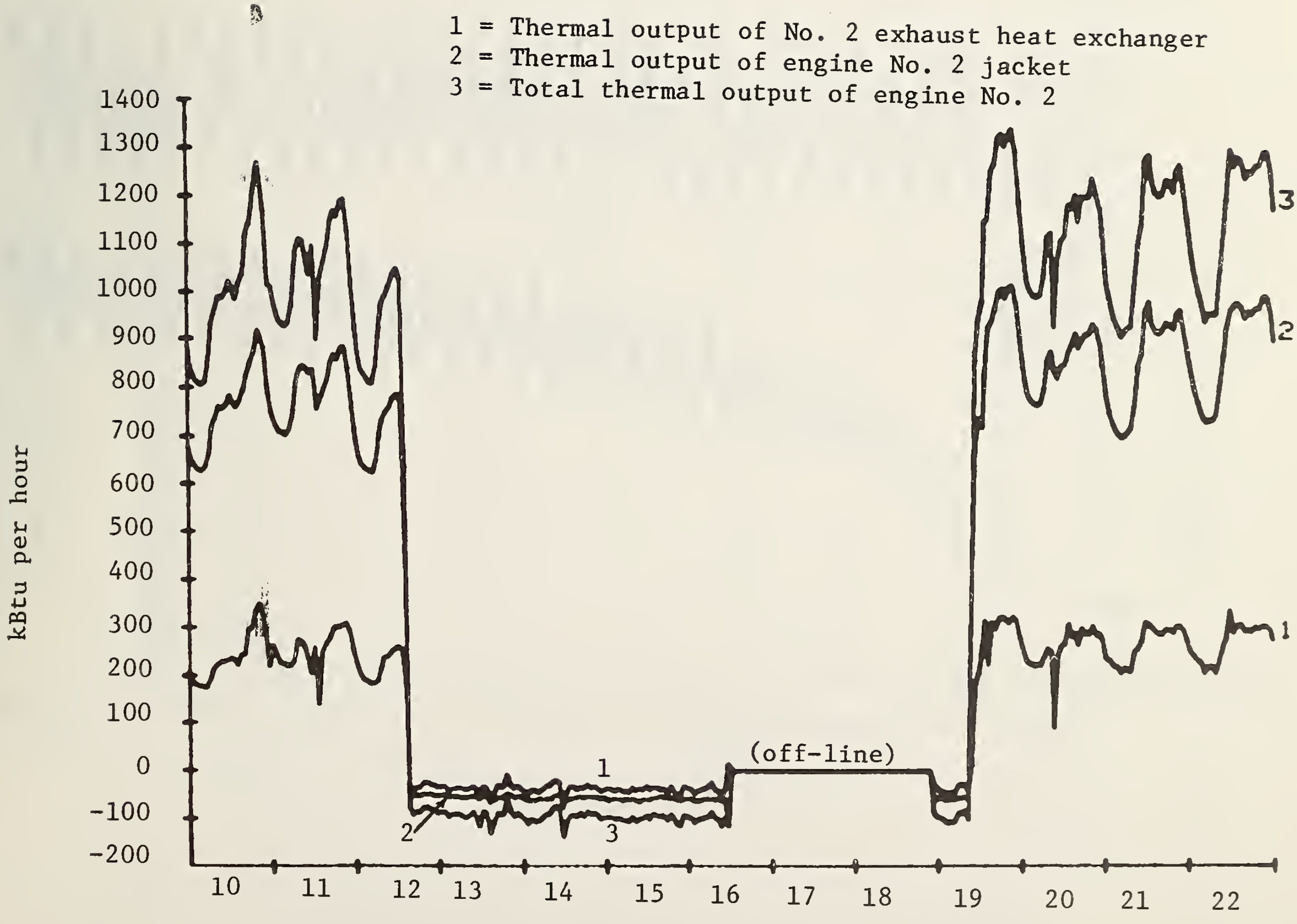

Figure 5-1. The thermal energy recovered (or lost) from engine No. 2 under three modes of operation: on-line, off-line and valved out of the PHW loop. See text for details.

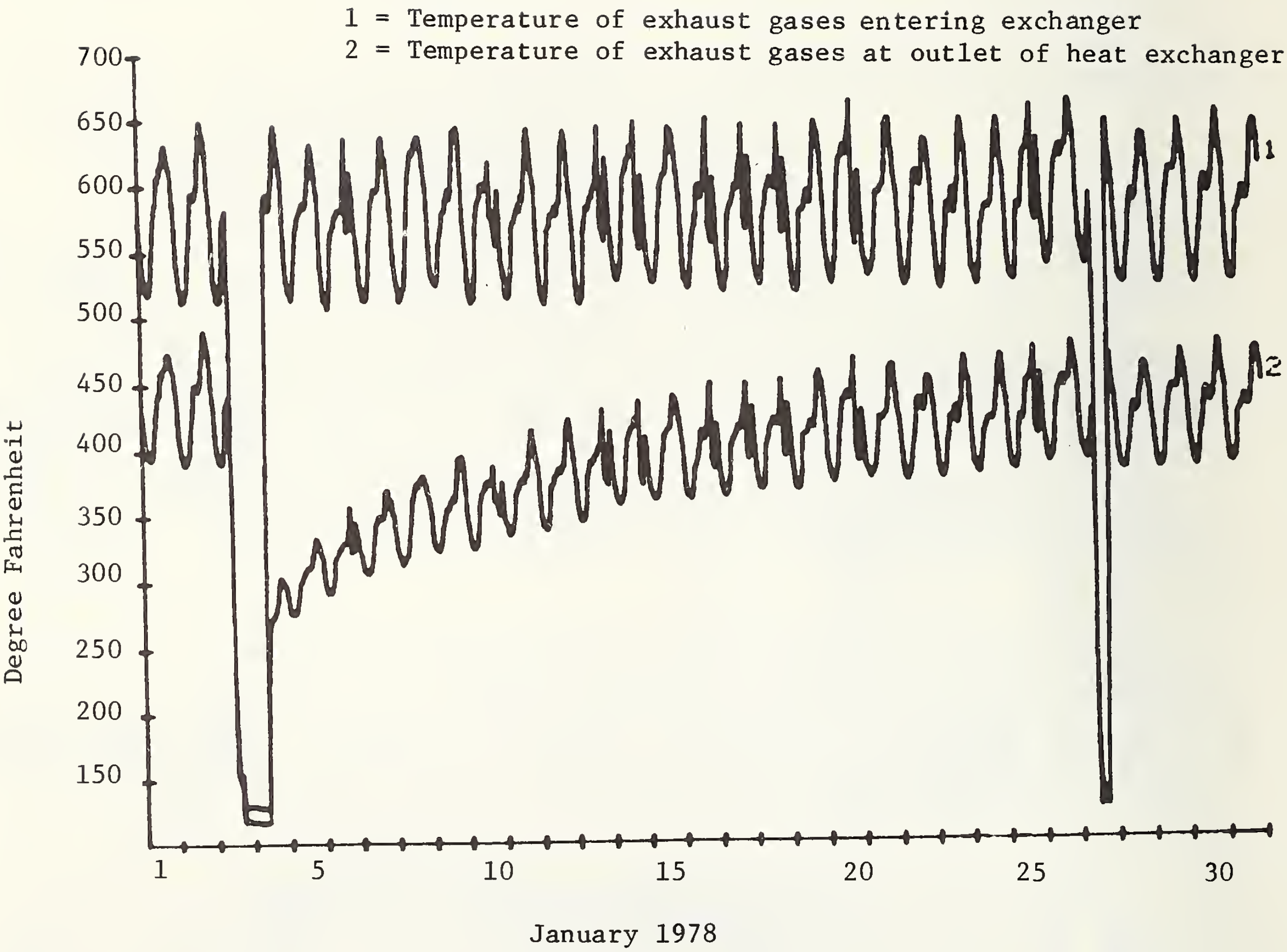

Figure 5-2. Temperature of exhaust gases from engine No. 2 entering and leaving the exhaust gas heat exchanger. The unit was taken off-line January 3, 1978, the exhanger cleaned, and the unit put back on-line January 4, 1978. The rapid accumulation of deposits in the tubes of the exchanger are indicated by the increase in the outlet temperature.

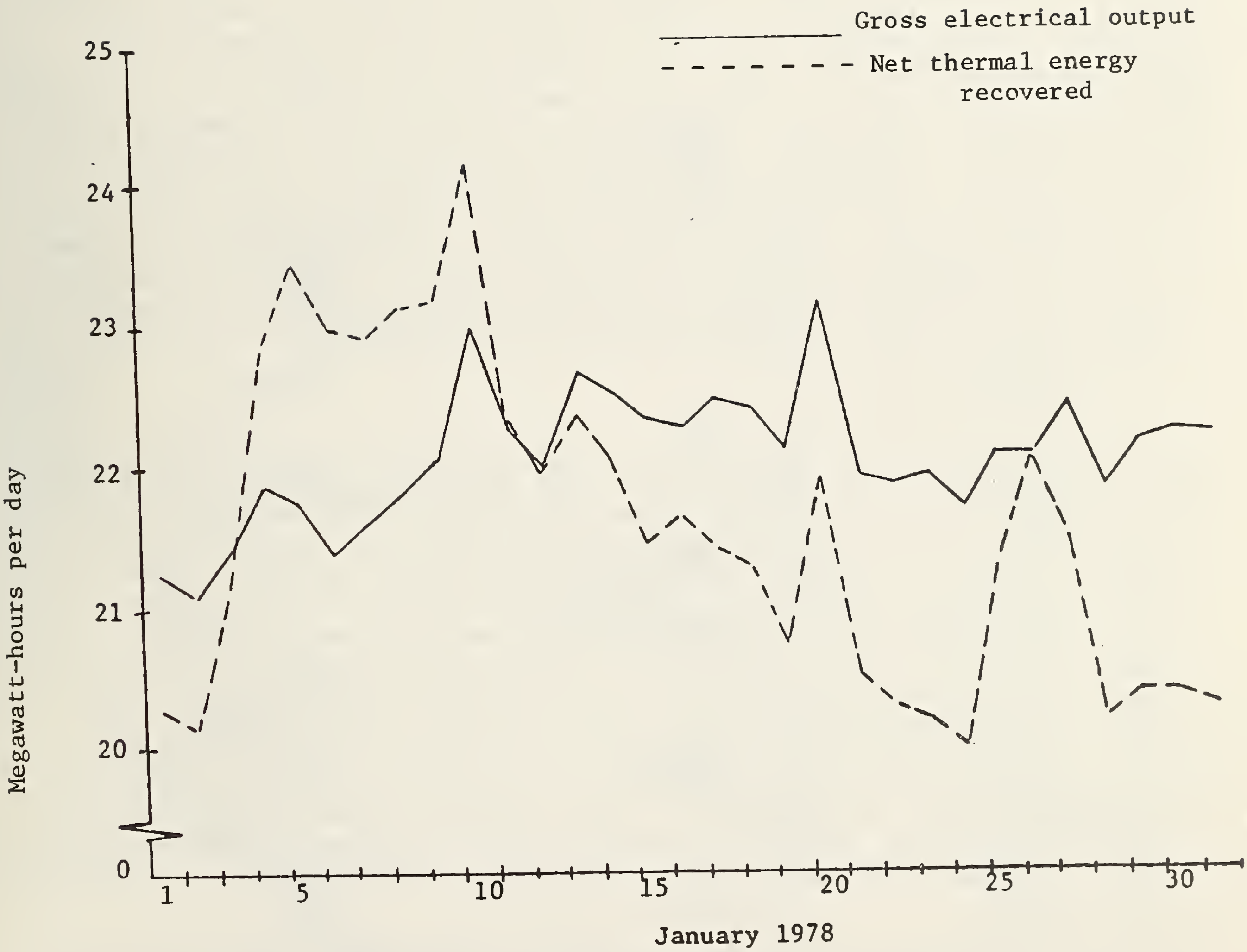

Figure 5-3. Gross electrical output and net thermal energy recovered from the bank of engines. The exhaust gas heat exchangers were cleaned during the period December 26, 1977 through January 3, 1978. On the January 25 and 26 the engines on-line were changed. Two engines with less deposites in their exhaust gas heat exchanger were put on-line and reflected the rise in the net thermal energy recovered from the engines. The overall effects of the deposits in the exhaust gas heat exchangers are reflected in these curves.

5.2 BOILER PERFORMANCE

The plant is equipped with two 13.4 MBtu (3.9 MW) oil fired, hot water boilers capable of meeting the thermal demands of the site without the thermal energy recovered from the engines. These boilers function with a reasonably high efficiency. However, there is always a constant loss from each boiler when the PHW is flowing through it. These boilers are operated in series in the PHW loop when both boilers are on-line. The valving and controls are arranged to allow either boiler to be taken out of the loop and either boiler to be put in the lead position when both boilers are in the loop. Figure 5-4 indicates the profiles for the output of both boilers during the month of January 1977, one of the coldest months recorded in history for the JCTE site area. It will be noted that the leading boiler did not exceed 75 percent of its rated capacity before firing the lagging boiler. During the 33 month period of DAS data covered by this report, both boilers were on-line for a total of 22 months.

5.3 CHILLER PERFORMANCE

During the three cooling seasons (1975, 1976, 1977) covered in this report, the COPs' of the absorption-type chillers in the plant were 0.401, 0.402, and 0.489 respectively. The expected COP of absorption chillers of this type is 0.60. An analysis of the data and the daily plant logs for these three cooling seasons indicated problems in seasonal and routine servicing and adjustment, most of which was performed under contract. For example, at the end of the 1975 cooling season, it was discovered that several large gaskets had been improperly installed in the chillers. Fragments of these shredded gaskets restricted the flows inside the chillers. During the 1976 season, the chillers appeared to operate in a somewhat erratic manner indicating faulty control and/or adjustments. Periods of very low COP's (0.2 to 0.3) were experienced for several days which were followed by short periods of higher COPs (0.50); still below the expected level. On September 21, 1976 a factory representative restored the chillers to normal operation by making several adjustments in the controls. Figure 5-5 presents the thermal input and output profiles showing the results of this action.

The 1977 cooling season yielded high COP's for the months of June, July, and August (0.496, 0.572 and 0.559 respectively). However, in September 1977 it was discovered that the nozzles in the cooling tower were clogged from scale originally formed on the inside of the pipes and the COP fell to lower values during the operation of removing, cleaning and replacing the nozzles.

Further analysis of the 1977 data indicated that 16 percent percent of the total cooling load was used for plant cooling. The size and location of the plant and the desire to make this plant more comfortable for maintenance and for the numerous groups of visitors that were expected to visit and tour this plant prompted the designer to provide cooling for the plant. If cooling were not provided for this particular plant, modification to the plant ventilating system would be required.

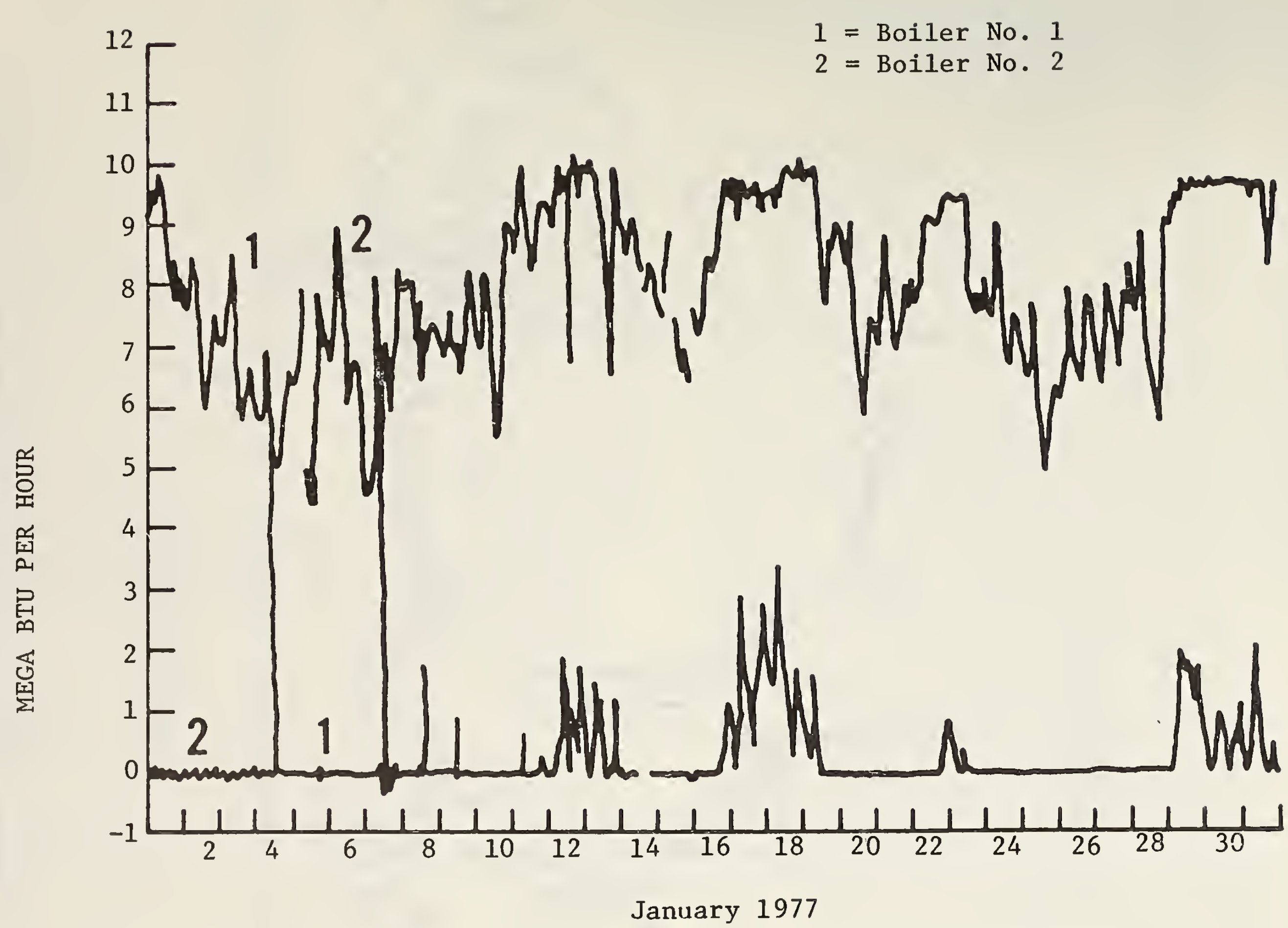

Figure 5-4. Thermal energy recovered from each of the boilers during one of the colder months recorded in meteorological data. The boilers are rated at 13.4 MBtu per hour (3.9MW). However, the controls apparently limited the output to 10 MBtu per hour.

NOTE: Boiler No. 1 was changed from lagging to leading position January 4, 1977.

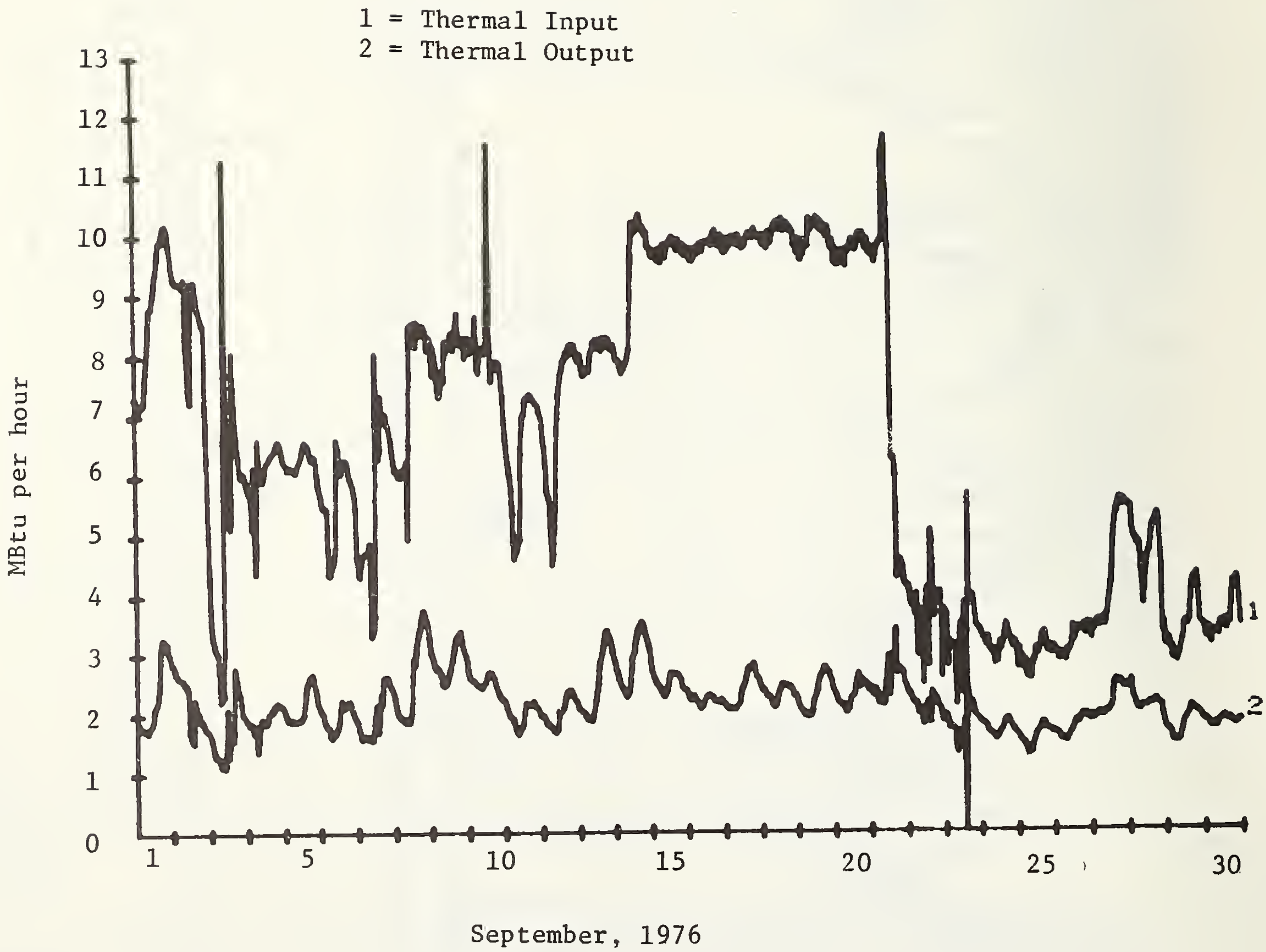

Figure 5-5. Profiles of thermal input and output of chillers in September 1976. The erratic functioning of the chillers is indicated during the first half of the month. On September 21, 1976, a factory representative restored the units to normal operation.

6. RELIABILITY EVALUATION

A study was made of the availability and quality of the utility services supplied by the plant to the site buildings. The electrical and thermal services were covered in this study. The availability of the services refers to the interruption of utility services to the customers. The quality of service refers to the acceptability of the service rendered.

6.1 RELIABILITY OF ELECTRICAL SERVICES

In general, the measured data indicate that the JCTE plant has the capability of being highly reliable and functioning within the availability targets set, and achieved, by many electric utility companies. These levels of reliability were not, however, achieved in the first and third years of plant operation due to plant outages attributable to the early debugging of plant equipment and a learning-curve period for plant personnel. The control system used in the electrical power generation portion of the plant was the principle source of equipment outages. If the JCTE plant data are to be used in reliability modelling, the existing control system should be carefully evaluated with reference to the present state-of-the-art of such control systems. The study also revealed the partly-attended operating status of the plant had an adverse effect on reliability to the extent of a three fold increase in the average interruption duration. Table 6-1 lists the interruptions for the period covered during this study. The fractional numbers of interruptions reflect the partial outages of the site. The time for the outages accounts for these partial outages.

The quality of the electrical services at the JCTE site were rendered at an acceptable level.

6.2 RELIABILITY OF THERMAL SERVICES

The availability and quality of the thermal services of the plant to the site were found to be well within an acceptable level with the exception of the chilled water supply which frequently reached a temperature that exceeded the desired maximum temperature limits.

Table 6-1. Summit Plaza Total Energy Plant Electrical Service Reliability

Year	No. of Interr.	Interr. Duration, Minutes Total	Average	Maximum
1974	12.8	2474	193	1869
1975	0.6	5	-	-
1976	11.6	992	86	249
1977	2.4	116	48	55

7. RESULTS OF ENVIRONMENTAL TESTS

On-site data were collected by the Oak Ridge National Laboratory for the National Bureau of Standards to determine the environmental effects of the JCTE plant on the air quality and noise. Measurements of air quality were made for a six week period in the summer and a six week period in the winter.

7.1 AIR QUALITY ASSESSMENT

Preliminary data and calculations showed that only NO_x emissions from the plant would be detectable in the form of ground level concentrations. Some ground level data were taken for CO, SO_2, THC (total hydrocarbons) and particulates, but only to characterize general air quality levels at the site. The ground level NO_x concentration contributions from the plant were expected to be influenced by the short exhaust stack, 62 ft (19 m) above ground, and by building-induced downwash of the exhaust plume due to the direction and velocity of the wind. The actual results indicated that some plume downwash occurred about 50 percent of the time at Summit Plaza.

Ground level concentration data were continuously taken during a winter and summer test period at several locations, roughly at the four compass points and at distances from 30 ft to 260 ft (9 m to 80 m) from the plant. Wind speed and direction data were also taken in part to allow separation of data into downwind and upwind data sets (i.e., TE plant affected data and background data). These data indicated that the annual average contribution of the TE plant to ground-level NO_x ranged from .03 ppm to .06 ppm above the background levels, depending on the direction and season.

U.S. Federal Air Quality Standards specify an annual arithmetic average concentration of .05 ppm for NO_2. Although incomplete data was obtained for NO_2, by applying measured NO_2/NO_x ratios to all data, it appeared that the incremental contribution of the TE plant to ground-level NO_2 was approximately .018 ppm to .028 ppm, substantially less than the standards permit. However the background NO_2 level for the site, without the influence of the TE plant, appears to be very near the maximum levels specified in the standards. Adding the TE plant in this circumstance has an adverse impact on the air quality.

7.2 NOISE LEVEL ASSESSMENT

Five surveys were conducted during July and August 1977. The diesel stack dilution fan and cooling tower fans were operating during all surveys. The engine-generators were the sources of the highest noise predominantly south of the plant. The engine exhaust fans were the second highest sources causing increased noise levels predominantly north of the plant. The noise contribution from these two most significant sources does not exceed the 65 dB(A) daytime limit of the local noise ordinances at any adjacent residential building. The nighttime noise level limit of 50 dB(A) for residential space is exceeded by the surrounding urban activities alone [55 dB(A)].

7.3 COOLING TOWER ASSESSMENT

The cooling towers used for waste heat rejection from the absorption chillers were assessed for potential environmental effects including chemical toxicity, plume visibility and nuisance effects of drift deposition. The cooling tower water is treated with a chemically benign additive and the plume is rarely visible during the season when the chillers are in service. Therefore, the major efforts of this assessment were directed toward the drift deposition and concentration characteristics. The results of these efforts indicated that the drift deposition of the cooling tower plume was indistinguishable from ambient concentrations of moisture and minerals. The drift loss was found to be at a very acceptable level of 1×10^{-4} percent when the towers were properly maintained.

During the period of this assessment, the cooling towers located on the roof of the plant were in the final stages of an unscheduled maintenance program. The results stated above reflect conclusions reached from measurements after this program was completed. Measurements made prior to the completion of the maintenance work reflected abnormally high drift losses resulting in spotty deposition on parked cars in the area of the plant. In general, the cooling towers require routine cleaning maintenance to preserve good flow distribution and low drift loss characteristics.

8. ENERGY ANALYSIS OF ALTERNATIVE SYSTEMS

A series of comparative analyses were performed to examine the differences in energy and economic impacts between the existing JCTE plant and other ways of providing equivalent energy services to the Summit Plaza buildings. The results of the comparative analysis of energy consumption are reported in this section. Twelve different energy systems were postulated. The systems were selected to cover a representative range of all technical options for the buildings at the Summit Plaza Site.

8.1 DESCRIPTION OF THE ALTERNATIVE SYSTEMS

Each of the twelve energy systems examined for Summit Plaza are briefly described below:

System No.

Total Energy Systems

1. The existing total energy plant at Jersey City including Caterpillar diesel engine-generators, oil-fired boilers and absorption chillers.

2. The existing JCTE plant with electric utility interconnecting to allow selling of power to the local power company.

3. Same as system 1 above except using medium-speed, higher efficiency diesel engines instead of the existing Caterpillar units.

4. Same as system 1 above except using combined absorption-compression chillers with the absorption chillers thermally energized by recovered heat.

Conventional Central Systems

5. A central plant similar to system 1 without on-site electric power generation and with electrically-driven compression chillers.

6. Similar to system 5 except using absorption chillers instead of compression chillers.

7. Similar to system 5 and 6 except using combined diesel-driven compression chillers and absorption chillers energized by recovered heat.

Conventional Building Systems

8. An individual mechanical system for each building using electrically-driven compression chillers, oil-fired boilers and hydronic distribution. Electrical energy purchased.

9. Similar to system 8 except using electric boilers.

Individual Unit Systems

10. Self contained through-the-wall terminal air conditioners with electrical resistance heat for each apartment. Electrical energy purchased.

11. A single heat pump for each apartment with forced air distribution.

12. A central air conditioner/electric resistance heat unit for each apartment with forced air distribution.

8.2 ENERGY EVALUATION

Energy consumption in terms of both fuel and electrical energy consumed on-site for each of the alternative systems described above was determined by means of a commercially available computer program. The program simulates in detail the performance and operation of each of the alternative systems in response to diurnal site load variation.

The availability of actual measured data from the JCTE plant presented the opportunity to "fine-tune" the computer simulation to more accurately model the existing plant (System 1). Obtaining an accurate model of system 1 improved the accuracy of other alternative system models since the site loads and many components were common to more than one system.

The energy consumption loads for secondary hot water, chilled water and site and plant electrical energy requirements for the specific months chosen for the comparison were obtained from tables 4-1 through 4-4. The measured values were compared to loads calculated by the program. Differences were expected in the heating and cooling loads because of the excessive site distribution losses described in the Final Report. The analysis presented in section 5 of this summary and in the Final Report determined the approximate magnitude of the anomalous losses and these values were used to normalize the actual JCTE data to provide a more valid comparison.

The results of the computer runs for each of the 12 systems are presented in table 8-1. The values listed reflect adjustments made in the computer program for the anomalies previously discussed. The results of the economic comparison of the alternative systems are given in section 10 of this summary.

Table 8-1. Calculated annual energy consumption of alternative systems

System	Fuel Oil Consumed	Energy Content[a)] of Fuel Oil	Electricity Purchased	Source Energy[b)] Consumed
	1000 gal	10^6 Btu	10^3 kWh	10^6 Btu
1	790.1	109,800	0	109,800
2	1182.1	164,300	(5,763)[c)]	97,400
3	727.5	101,100	0	101,100
4	763.3	106,100	0	106,100
5	284.2	39,500	8,270	134,700
6	375.7	52,220	7,955	143,800
7	323.6	44,980	7,969	136,700
8	284.2	39,500	8,527	137,700
9	0	0	17,890	206,000
10	0	0	17,790	204,900
11	0	0	15,180	174,800
12	0	0	17,790	204,900

a) converted at 139,000 Btu/gallon.

b) electrical energy converted at 11,515 Btu/kWh (29.6% efficiency).

c) electricity sold to utility; counted as energy credit at power plant.

9. JCTE COST DATA AND ANALYSIS

The actual economic data collected for the Summit Plaza TE plant are presented and analyzed in this section to develop data for use in the system comparisons and to provide "raw" data for use by others.

A review of the economic data is also made to show the effect of anomalous conditions on the economic data. Anomolous conditions include equipment performance problems, improper or inoptimum operating and maintenance practices, unique institutional factors, etc.

The actual costs are presented that have been incurred as a result of designing, constructing, owning and operating the total energy plant at Summit Plaza. The types of actual costs considered include the operating and maintenance (O & M) costs from the initial plant start-up in January 1974 through November 1977; initial capital incurred beginning in late 1971 and capital improvements since plant start-up; and owning costs other than capital investment.

The O & M costs are condensed into the following categories:

1. Fuel
2. Contract Maintenance
3. Direct labor and overhead
4. Plant burden
5. Direct Material
6. Miscellaneous

A summary of the O & M costs for 1977 are presented in table 9-1. The importance of the cost of fuel is evidenced by its 59.1 percent share of the total costs. Unit fuel costs in 1977 were approximately 0.39 $/gal.

Capital equipment costs represent the initial investment as well as capital improvements and replacements during the life of the plant covered by this report. These costs are reported in the following categories:

1. Engine-generator
2. Mechanical system
3. Electrical system
4. Distribution
5. Central equipment building (plant)
6. Design Fee

The actual initial costs are presented in table 9-2. These costs were incurred during plant construction which took place from November 1971 through mid-1974. No cost is included for the cost of the land occupied by the plant.

The owning costs other than capital financing consists of expenditures for property taxes and property insurance by the site owner, Starrett Housing Corporation. These items are based on the entire Summit Plaza complex and do not separately include the TE plant. The actual expenditures for real estate

Table 9-1. Direct O & M costs - 1977 Summary

(December 1976 - November 1977)

Cost Category	Subsystem								Plant Total	
	Electrical		Heating		Cooling		PTC			
	$	%	$	%	$	%	$	%	$	%
1. Fuel	245,407	63.4	127,684	65.7	0	0.0	0	0.0	373,091	59.1
2. Contract Maint.	37,672	9.7	11,288	5.8	9,213	24.6	3,317	27.9	61,490	9.7
3. Direct Labor + OH	57,090	13.4	32,962	16.9	13,919	37.3	5,209	53.7	104,180	16.7
4. Plant Burden	37,026	9.5	17,123	8.8	7,647	20.5	2,643	22.2	64,438	10.2
5. Direct Material	14,821	3.8	4,878	2.5	6,270	16.8	642	5.4	26,611	4.2
6. Miscellaneous	962	0.2	553	0.3	314	0.8	96	0.8	1,925	0.3
TOTAL	387,978	100.0	194,487	100.0	37,362	100.0	11,907	100.0	631,735	100.0

Table 9-2. Capital cost summary
Actual construction costs including overhead & profit

Thousands of Dollars

Cost Category	Subsystem				Total
	Electrical	Heating	Cooling	PTC	
Engine-Gen.	$316	-	-	-	$316
Mechanical	132	553	714	85	1,484
Electrical	213	-	-	-	213
Distribution	214	86	110	713	1,123
CEB Envelope	208	130	148	109	595
Design Fee	52	39	49	Included above	140
TOTAL	$1,135	$808	$1,021	$907	$3,871

taxes are not influenced by the value of equipment used for providing utility services. In presenting the actual costs as experienced for the JCTE plant, this report includes no portion of the total Summit Plaza costs for real estate taxes.

9.1 UNIT ENERGY COSTS

Unit costs for each of the energy commidities provided by the plant were calculated using the actual O & M and capital cost data. Unit costs for JCTE are provided primarily as a convenient, widely understood means of presenting the actual cost data. These data can be used for various types of comparisons. However, if comparisons are to be made using JCTE actual unit cost data, care must be exercised to insure that:

1. All relevant costs are included or that similar physical/cost accounting boundaries are drawn so that comparable cost items are included;

2. Building complexes are somewhat similar in their load patterns; and

3. Anomalous conditions are considered.

The unit cost results are shown in table 9-3 as an aggregate 3-year summary of subsystem unit costs. Year by year data do not vary significantly from the aggregated values. In all cases, the cost components of fuel, other O & M and capital recovery are provided to facilitate comparison with data which may not include capital recovery or which may be based on different unit costs for fuel.

Table 9-3 shows a very high unit cost for chilled water and moderately high unit costs for electrical energy and hot water. The high cost for the chilled water reflects the hight capital recovery associated with a system which operates only four months of the year and the high fuel costs resulting from the low performance efficiencies discussed previously.

9.2 ASSESSMENT OF TYPICALITY OF DATA

Engineering data and observations were used in an analysis of the cost data to identify the major variables which have affected actual plant costs, conduct an assessment of the typicality of the cost data, and provide cost adjustments for typical conditions. The typicality of JCTE economic data should always be considered in analyses which directly use JCTE overall economic results for comparison or which use the JCTE individual cost component data to synthesize costs for other TE plants. Some of the areas that are reflected in the actual data are discussed below.

The total O & M cost has continuously increased since January 1974 for fuel and non-fuel components. Fuel cost increases have resulted from both increased fuel usage and from rising unit costs for fuel. Fuel usage is largely affected by site/plant loads and by equipment performance. For non-fuel O & M costs, general increases in costs for on-site labor, contract maintenance and materials costs have been experienced since the plant was put in service in January 1974.

Table 9-3. Unit cost of site thermal and electrical energy

March 1, 1974 through November 30, 1977

Cost Category	Electricity	Hot Water	Chilled Water
	¢/kWh	$/MBtu	$/MBtu
Fuel	1.92	3.90	10.08
Other O & M	1.22	2.60	6.80
Capital recov.	1.02	2.87	18.86
TOTALS	4.16	9.37	35.74
Site energy delivered MWh or Btu	18,210	112,000	21,540

costs have been experienced since the plant was put in service in January 1974. The combined cost for on-site labor and contract maintenance has also changed over time since as many of the O & M tasks originally done by contract have been taken over by plant personnel.

Section 5 of this summary identifies several areas where equipment performance has not met expected levels. These items may also have a significant effect on O & M costs. Foremost among these is the chiller and heat recovery performance. In addition, the excessive site distribution losses reported in the Final Report directly affected the site loads imposed on the TE plant and should be considered when making comparisons with systems serving a similar site but for which no load data are available.

Capital costs are influenced by the basic design approach, by government imposed plant design requirements, by local codes and by institutional factors such as construction/procurement requirements for government-funded projects. Several specific design decisions were identified which have influenced costs. For example, in the design stage, a potentially more efficient combination of absorption and compression chillers was examined but rejected because of expected reliability problems with engine-driven centrifugal chillers.

10. ECONOMIC EVALUATION OF ALTERNATIVE SYSTEMS

The economics of the Summit Plaza TE plant were investigated on the basis of a comparison with the estimated costs of twelve alternative systems described in section 7.

10.1 CAPITAL COSTS

The capital cost of each alternative system was estimated based on each piece of mechanical and electrical equipment in the plant. The type, size and quantity was costed from cost estimating handbooks and manufacturer's data. These data were based on the cost levels current as of January 1, 1976.

A summary of the capital cost data is provided in table 10-1. These data indicate that the twelve systems fall into four cost categories which are equivalent to the four basic design approaches; namely:

1. Total energy systems - approximately $7.3 million
2. Conventional central systems - approximately $5.9 million
3. Individual building systems - approximately $5.0 million
4. Individual apartment systems - approximately $4.1 million

The capital costs shown in table 10-1 include all elements for each system as required for the Summit Plaza site. In the central systems (categories 1 and 2 above), the data include all relevant mechanical and electrical equipment within the buildings as well as the plant. Therefore the cost of System 1 in table 10-1 is not just the cost of the total energy system plant as shown in section 9 and cannot be compared with the actual TE cost data of table 9-2.

The three "individual apartment" type systems (Systems 10-12) were considered to have a shorter life (10 years) compared to the 20 year life of the larger industrial-oriented type of equipment used in the other systems. The replacement cost (in year 10) for these systems is also shown in table 10-1.

10.2 OPERATIONAL AND MAINTENANCE COSTS

Maintenance cost estimates for each alternate system were based on quotations provided in 1977/1978 by maintenance service contractors for the specific pieces of major equipment used in each system. For each system, all equipment was considered in developing the maintenance costs including the building distribution and terminal units for the central systems. These data are considered to be an excellent source of relative costs between alternative systems. The costs for on-site operating labor, labor overhead, and plant burden were estimated based on actual JCTE data. Table 10-2 lists the O & M costs for each of the twelve systems. The O & M costs for the JCTE were adjusted for the pneumatic trash collection (PTC) system (not included in system 1). The O & M costs were also adjusted for anomalous conditions discussed in section 9.

Table 10-1. Summary of capital costs

System No.	Description	Cost
Initial Investment		$1,000
1	Total Energy - Existing	7,331
2	Total Energy - Existing - Selling Power	7,331
3	Total Energy - High Efficiency Engines	7,947
4	Total Energy - Diesel and Absorption Chillers	7,318
5	Central Plant - Electric Chiller - Oil Burner	5,836
6	Central Plant - Absorption Chiller - Oil Burner	5,861
7	Central Plant - Diesel and Electric Chillers	6,621
8	Building Plant - Electric Chiller - Oil Burner	5,027
9	Building Plant - Electric Chiller and Boiler	4,963
10	Individual Apartment - Through-the-wall Air Conditioners with Electric Resistance Heat	4,120
11	Individual Apartment - Central Heat Pump	4,197
12	Individual Apartment - Central Air Conditioner and Electric Resistance Heat	3,989
Replacement Cost		
10	Individual Apartment - Through-the-Wall Air Conditioners with Electric Resistance Heat	1,294
11	Individual Apartment - Central Heat Pump	1,125
12	Individual Apartment - Central Air Conditioner and Electric Resistance Heat Heating & Cooling	919

Table 10-2. Operation and maintenance cost estimates for alternative systems

System Number	Maintenance[a)] Cost	Plant[b)] Burden	Operating[c)] Labor Cost	Miscellaneous[d)]	Total O & M Cost less Fuel and Electricity
	$1,000	$1,000	$1,000	$1,000	$1,000
1	124.2	23.3	85.0	18.6	251.1
2	145.0	23.3	85.0	21.1	274.5
3	124.2	23.3	85.0	19.0	251.5
4	124.2	23.3	85.0	17.7	250.2
5	80.6	12.3	73.9	12.4	179.2
6	80.6	12.3	73.9	14.6	181.4
7	87.4	12.3	73.9	15.4	189.0
8	83.7	12.3	55.4	11.1	162.5
9	82.4	12.3	55.4	10.1	160.2
10	80.2	12.3	18.5	8.5	119.3
11	70.4	12.3	18.5	8.1	109.3
12	68.1	12.3	18.5	7.8	106.7

a) Based on detailed cost analysis

b) Based on JCTE data.

c) Including labor overhead, based on JCTE data and trends.

d) Consists of property insurance and plant water use.

10.3 FUEL AND ENERGY COSTS

The quantity of fuel and electrical energy consumed by the alternative systems was previously established in section 8. These data, when combined with unit energy costs, directly result in the total annual energy costs for each of the alternative systems and are listed in table 10-3. The unit energy costs for the number 2 fuel oil used in on-site combustion equipment (Systems 1 through 8) are based on the actual unit cost of fuel used by the TE plant for 1975 and 1976 ($2.40 per million Btu). Significant regional differences in the cost of oil can exist and should be considered in a national-perspective evaluation. Electrical unit costs were based on actual utility rate schedule for large user service (which provides the lowest-cost power to the site). The unit cost is different for each system, being dependent on demand and consumption data, space heating and night use credits. Utility electric rates also include a rate adjustment charge. Values of 3.2 to 3.5 ¢/kWh resulted from the calculation.

10.4 ECONOMIC EVALUATION

An economic evaluation was carried out by calculating the value of four measures of economic viability for each of the twelve alternative systems.

The basic cash flow data consists of capital investment costs and annual costs for each of the alternative systems. These data are shown in table 10-4. The capital investment costs in this table are based on the data listed in table 10-1 and include the present worth of the replacement cost for Systems 10, 11 and 12. Annual costs for each of the twelve alternative systems include the sum of the total O & M costs from table 10-2 and total energy costs from table 10-3.

The O & M cost data included in the figures of table 10-4 are direct expenditures in the first year of operation. Income tax payments or any effects of financing are not included in these data. The effect of inflation on annual costs in future years is also not included.

The data of table 10-4 were used to develop incremental data using the lowest cost system, System 12 as the baseline and the results are shown in table 10-5. Payback period and return on investment (ROI) were calculated and compared to estimated decision criteria. ROI considered all costs over a 20-year period, including income taxes and inflation rates of 12 percent and 8 percent, respectively, for energy commodities and all other goods and services.

The following conclusions are apparent:

System 8, using fuel oil boilers and electric chillers is a very attractive alternate system.

- The added investment for System 11 (heat pump), System 5 (central plant-electric chiller and oil boiler) and System 6 (central plant absorption chiller and oil boiler) can be attractive under certain business conditions.

Table 10-3. Energy cost for alternative systems

System Number	On-site Fuel Cost[a)]	Utility Electricity Cost	Total Energy Cost
	$1,000	$1,000	$1,000
1	263.5	0	263.5
2	394.3	145.3[b)]	249.0
3	242.6	0	242.6
4	254.6	0	254.6
5	94.8	289.9	384.7
6	125.3	277.4	402.7
7	107.9	277.9	385.8
8	94.8	297.1	391.9
9	0	572.2	572.2
10	0	574.2	574.2
11	0	497.1	497.1
12	0	574.2	574.2

a) Unit cost of on-site fuel is the same for all systems, $2.40/10^6$ Btu.

b) Credit for electrical energy sales; at a sales price of 2.52 ¢/kWh.

Table 10-4. Actual cash flow data for alternative systems

System Number	Capital Investment[a]	Before Tax Annual Cost[b]
	$1,000	$1,000
1	7,331	514.6
2	7,331	542.2
3	7,947	494.1
4	7,318	504.8
5	5,836	563.9
6	5,861	584.1
7	6,621	574.8
8	5,027	554.4
9	4,963	732.4
10	5,414	693.5
11	5,321	606.4
12	4,908	680.9

a) Values for System 10 through 12 include the value of capital replacements in year 10.

b) First year cost; from tables 10-2 and 10-3.

Table 10-5. Comparison of alternative systems using several incremental investment measures

System Number	Initial Investment Premium	Simple[a)] Payback Period	Discounted Nominal ROI[b)]
	%	Years	%
1	49.4	14.6	11.8
2	49.4	17.5	10.3
3	61.9	16.3	10.6
4	49.1	13.7	12.2
5	18.9	7.9	17.2
6	19.4	9.8	15.3
7	34.9	16.2	10.7
8	2.4	0.9	68.8
9	1.1	-	-
10	10.3	-	-
11	8.4	5.5	19.9
12	0	-	-

a) Before income taxes.

b) Including income taxes and inflation.

- The large investment premiums associated with the TE system (about +50 percent) are not attractive business investments for most conditions.

Other analysis, were conducted to show the sensitivity of the economic results to changes in assumption on local JCTE conditions.

An analysis based on real ROI (i.e. no annual inflation considered) showed nearly the same results as the other criteria. Including the investment tax credit (made under some business scenarios) also did not alter the basic conclusions.

Again, the reader is encouraged to refer to the Final Report for further details.

NBS 114A (REV. 9-78)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO.	2. Gov't. Accession No.	3. Recipient's Accession No.
	NBSIR 82-2483		

4. TITLE AND SUBTITLE

Performance Analysis of the Jersey City Total Energy -- Executive Summary

5. Publication Date

April 1982

6. Performing Organization Code

7. AUTHOR(S)

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8. Performing Organ. Report No.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, DC 20234

10. Project/Task/Work Unit No.

11. Contract/Grant No.

12. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS *(Street, City, State, ZIP)*

Department of Housing and Urban Development
Division of Energy, Building Technology and Standards
Office of Policy Development and Research
Washington, D.C. 20410

13. Type of Report & Period Covered

14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

Under the sponsorship of the Department of Housing and Urban Development (HUD), the National Bureau of Standards gathered engineering and economic data from an apartment/commercial complex located on a 6.35 acre (2.6 hectare) site in Jersey City, New Jersey.

The National Bureau of Standards was responsible for instrumenting the plant and site buildings and recording engineering data utilizing an automatic data acquisition system (DAS). The DAS was put on-line in April 1975.

Economic, reliability and environmental data were also collected and analyzed by NBS in conjunction with an analysis of the engineering data. This report presents an "Executive Summary" of the final report on the performance analysis of the Jersey City Total Energy Project. The reader is encouraged to refer to that final report for further details.

The analysis of the engineering data clearly indicates a significant savings in fuel by using the total energy concept in the plant. Several areas were also identified by this analysis where minor modifications in the plant operation could result in additional fuel savings. Three of the modifications have already been incorporated in the present plant operational procedures.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Absorption chillers; boiler performance; diesel engine performance; engine-generator efficiency; integrated utility system; total energy systems-economic and engineering analysis; waste heat recovery

18. AVAILABILITY [X] Unlimited

[ ] For Official Distribution. Do Not Release to NTIS

[ ] Order From Sup. of Doc., U.S. Government Printing Office, Washington, DC 20402, SD Stock No. SN003-003-

[X] Order From National Technical Information Service (NTIS), Springfield, VA. 22161

19. SECURITY CLASS (THIS REPORT)	21. NO. OF PRINTED PAGES
UNCLASSIFIED	59
20. SECURITY CLASS (THIS PAGE)	**22. Price**
UNCLASSIFIED	$9.00